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# FACILITIES ENGINEERING SUPPORT AGENCY

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REPORT FESA-T-2099

# EFFECT OF TEMPERATURE SET-BACK ON HEAT PUMP PERFORMANCE

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Prepared For:

U. S. ARMY FACILITIES ENGINEERING SUPPORT AGENCY
TECHNOLOGY SUPPORT DIVISION
FORT BELVOIR, VIRGINIA 22060

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Fort Belvoir, Virginia 22060

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This report documents an analysis which shows that energy savings and corresponding cost savings could be realized by employing set-back strategies dependent on location, heat pump capacity and amount of set-back.

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## SUMMARY

The results of our analysis show that energy savings and corresponding cost savings which could be realized by employing set-back strategies are dependent on location, heat pump capacity, and amount of set-back. While some manufacturers may believe that it is not economical regardless of the situation[7], many feel this is not the case.[8] It is probable that the right combination of outdoor temperature, heat pump capacity, and amount of set-back make savings possible. However, energy savings do not guarantee cost savings. The decision on priorities must be made before set-back is initiated. And because cost may be the deciding factor in most cases, the life cycle cost becomes an important quantity.

The remainder of the report deals with the advantages and disadvantages associated with set-back of thermostats for heat pump systems. The conclusions which this study has lead to are:

1. Further model studies and field data must be obtained before savings predictions can be taken as completely reliable and accurate.

2. Microcomputer controlled thermostats are not widely available for heat pump systems. They must become available, at a cost effective price, before set-back becomes accepted on a popular basis.

3. Savings are mostly dependent on outdoor temperature, heat pump capacity, and amount of set-back.

4. Energy savings are greater in percent in warm climates but greater in total consumption savings in cold climates. Therefore, since fuel costs are the main consideration, cost savings will be greater in percent in cold climtes.

5. Percent energy savings can be reasonably predicted without a complex computer model.

Thermostat set-back of air-to-air heat pumps has been a controversial subject for several years. With a conventional fixed-capacity heating system any reduction in thermostat set-point will usually give a corresponding proportional energy savings.[9] A heat pump in the heating mode does not operate on the same principle. The morning recovery period energy consumption sometimes can offset the savings achieved at night.[10] In addition, a peak demand occurs in the morning when the thermostats are set up, a consideration which is not beneficial to those Army installations which generate their own electricity.

Because of these problems and the complexity of air-to-air heat pumps systems, the exact energy savings are rather difficult to assess. It was the objective of this study to determine the energy savings and life cycle costs of heat pump systems employing thermostat night set-back. Comparisons between alternative systems and conventional presently used systems as well as availability, reliability and safety code compliance were also studied.

The procedure used was to evaluate all previous literature on night set-back of heat pumps, confirm the latest opinions of noted experts, and independently analyze life cycle data based on DoE projected energy costs and figures for performance, availability and reliability.

## PREFACE

Mr. P. B. Bruce, engineer, provided computer assistance and inputs for the life cycle economics segment. Additional, valuable information was obtained through communication with the following persons:

Dr. Charles Bullock, Program Manager, Research Division, Carrier Corp., Syracuse, New York

Mr. Lorne Nelson, Honeywell, Inc., Minneapolis, Minnesota

Dr. R. Howell, Professor, Dept. of Mechanical Engineering, University of Missouri-Rolla, Rolla, Missouri

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## INTRODUCTION

The practice of setting-back thermostats during the heating season has generated a large amount of feedback since its wide spread acceptance. Several facts have been recognized. Obviously, lowering the indoor temperature decreases the heating load. Lowering the indoor temperature affects the comfort of the occupants. It is an effective method of reducing building heat loss and fuel consumption of conventional fixed capacity heating systems (i.e., fossil fuel fired and electrical resistance heating systems).[11] The practice of lowering the indoor temperature only at night is a subject which is even more controversial. Very few facts have been recognized. It lowers the building heating load. It requires a morning recovery period during set-up of the thermostat. This, in turn, may pose a demand problem for the utility. The problems that can be expected differ vastly depending on the types of heating system. Although climatological, technological, and reliability considerations are important, the most important single factor is the type of heating system. Most experts concede that the set-back, whether continuous or night only, of fixed capacity systems is a relatively simple problem. This is not true for set-back of air-to-air heat pump thermostats.

It is the primary objective and purpose of this report to assess the advantages and disadvantages of setting-back thermostats with heat pump systems. Obviously, this is not an easy task. The subject is very complex, especially when night set-back is the major topic. Renowned experts in the heat pump, controls and teaching fields are still in disagreement about the economics of heat pump night set-back. To fully understand the reasons for these disagreements, some background information will be beneficial.

### Fixed Capacity System Characteristics

Fixed capacity systems refer to those systems which produce space heating independent of climate. In other words, fixed capacity systems are those systems which convert fuel directly into heat and are totally dependent on the fuel used and the system efficiency for their corresponding capacities.

Consider this example. A gas furnace uses natural gas with a heating value of 20,000 BTU per pound. The furnace burns one pound per hour at an efficiency of 70%. (For sake of simplicity, duct losses are neglected.) By using the following equation, HEAT SUPPLIED TO BUILDING = (HEATING VALUE)(EFFICIENCY)(MASS FLOW RATE), The heat supplied is calculated as:

$(20,000\ \frac{BTU}{lb})(.70)(1\frac{lb}{hr}) = 14,000\frac{BTU}{hr.}$ OR 1 1/6 TONS, where a ton is defined as $12,000\frac{BTU}{hr.}$ The absolute best this system can do if the efficiency, fuel used, and mass flow remain constant is to heat with a capacity of 1 1/6 ton. Even if the efficiency could be improved to 100 percent, the best the system would do would be to produce 20,000 BTU/lb of fuel. The capacity is "fixed" by the fuel and the system characteristics. The outdoor temperature affects the building heat load. The outdoor temperature does not adversely affect the efficiency of the system. This is an important point when considering whether set-back at night is economical. Gas furnaces are certified by the American Gas Association and are tested by ANSI (American National Standard Institute) procedures to have a combined combustion and heat exchange efficiency of 75 percent at full-load steady-state operation. There are numerous assertions that the seasonal fuel utilization efficiency of gas and oil-fired residential heating systems is 35 percent to 50 percent.[12] It is interesting to note that 85 percent of all residential heating systems are combustion type systems.

Unit electric resistance heating systems are also fixed capacity systems. It is usually assumed that all of the electrical energy is converted to heat energy and then deposited to the room. Because of this assumption, the system efficiency is taken to be 100 percent. The fuel utilization efficiency is then equal to the efficiency at which the electricity is generated. The national average of 32.6 percent together with an 89 percent distribution efficiency makes the fuel utilization efficiency of electrical resistance heating systems 29 percent.[13]

## Heat Pump Systems

Heat pumps, although they also employ electricity as the primary fuel, are unique in a number of ways. Most notably, they have the ability to provide space heating in the winter and cooling in the summer. They are more complex than fixed capacity systems. As a result, maintenance and investment costs are greater. In addition, less is known about their operating characteristics under various conditions. They are not fixed capacity systems because their efficiency, or coefficient of performance, changes as the outdoor temperature changes. And as the efficiency changes, the capacity also changes. Another condition which effects COP (total work out/total energy in) is defrost. A heavy buildup of frost on the outdoor coil adversely effects COP and so does the efficiency of the defrost operation. In short, an increase in moving parts causes a decrease in reliability and an increase in use of electrical resistance heat causes a decrease in COP. Since COP is typically no less than 1.50, the fuel utilization is typically no less than .29 (1.50), or 0.435 (43.5%). Duct losses are usually greater for heat pumps than fixed capacity systems but still not large enough to significantly reduce FUE (fuel utilization efficiency). Many articles are currently available which present an up-to-date review of heat pump characteristics.[14,15,16,17]

Factors Effecting Set-Back

The factors which effect set-back potential savings most importantly are outside temperature, amount of set-back, and control scheme. Lower outdoor temperatures ~~crease the heating load of the building. Also, the efficiency of fixed capacity systems is increased because of increased on-time. Heat pumps are different. Although compresor on-time does increase COP, the lower outdoor temperature significantly decreases capacity. As a result, the need for less efficient electric resistance heating is increased, reducing the overall COP. During the morning recovery period this problem is exaggerated. Usually the coldest part of the day is encountered when recovery to normal temperature is desired. At this point, the other two major factors become evident. If the amount of setback is small, the recovery period is shorter. The comfort level is reached quicker, the peak demand is smaller, and the use of electric heat is decreased. The energy savings acrued during the night also are smaller. The savings will be greater if the amount of setback is large ($10^{o}F$ or more). However, the recovery period will be long, causing poor comfort conditions, increased peak demand, and increased possibilities that energy savings will be defeated. Apparently, there is an optimum setback amount to produce greatest energy savings. The control scheme is of great importance when considering morning recovery. In general, the best control scheme is one which most effectively decreases use of electric resistance heat, increases compressor on-time, and maintains comfortable living conditions while reducing peak demand. To accomplish this complex task, the controls will probably require an override capability which could be triggered at regular intervals.

Previous Setback Studies

The results of previous setback studies, which have been conducted by several manufacturers of heat pumps and controls will be discussed in the literature survey section.

Temperature setback is a generally effective technique to reduce heating energy consumption. Whenever the space temperature is lowered and raised to correspond to occupancy schedules, the average space temperature and heat load will be lower relative to a constant comfort temperature. However, the energy conservation related to setback is dependent on the type of heating system. An electric resistance heating system is immune to inefficiencies caused by temperature variations since it operates at 100% efficiency all the time. A fossil fuel heating system's efficiency is inversely proportional to the number of operating cycles. Therefore, during morning warmup, the furnace runs continuously for long periods of time and is operating at its optimum steady state efficiency. Setback with a fossil fuel heating system actually improves the seasonal efficiency of the heating system as well as lowers the average heat load. Unfortunately, heat pumps do not follow this line of logic. While the actual heat load will be lower using setback, the energy consumption and cost may increase with the heat pump. The paradox occurs during morning warmup when the electric resistance backup heaters are automatically switched on by the 2-stage room thermostat (assuming conventional control scheme). This happens because the heat pump can adequately maintain room temperature but not rapidly raise the temperature when desired during morning recovery. The conclusions that may be reached concerning temperature setback are:

1. Electric resistance heating systems such as electric baseboard, will benefit from setback in a logical straight forward manner.
2. Fossil fuel heating systems will receive maximum efficiency benefits from setback.
3. Heat pump systems present more complex and controversial problems than do fixed capacity systems.

This report adresses this last conclusion and presents up-to-date heat pump setback information.

## LITERATURE SURVEY

The literature survey was conducted by Ms. Judith Gerber who is chief librarian of the Johns-Manville Research and Development Information Center. The principle resources were computer based searches. The sources reviewed in April of 1980 were:

COMPENDEX - Engineering Index

GPO Monthly Catalogue - Superintendent of Documents. U. S. Government Printing Office.

ISMEC (Information Services in Mechanical Engineering). Data Courier.

NTIS - National Technical Information Service. U. S. Department of Commerce.

Abstracts of over 200 heat pump and controls references were reviewed and the complete texts of 54 papers were read. Only three references were determined as critically pertinent to heat pump setback. About a dozen other references contained some useful informatin. The ASHRAE handbooks (Systems - 1980 and Fundamentals - 1977) were very useful. The most pertinent reports were also found in the ASHRAE Journal.

The Reference Section refers to footnoting throughout the report. Bibliography I refers to references used for the report but not quoted in the report. Bibliography II is an all-inclusive bibliography containing all references which are related to the subject of heat pumps or control of heat pumps.

Following is a reproduction of the conclusions section excerpted from the three most pertinent references. The remaining useful references were used throughout but their inclusion here was deemed unnecessary.

> The user of a residential heat pump can, by reducing indoor temperatures, decrease energy consumption for space heating by about the same percentage as the user of a fixed capacity heating system. Further reduction of temperature at night will produce additional savings, with a heat pump, but not by as great a percentage as may be achieved with a constant capacity system. The concern that increased use of auxiliary resistance heaters during the morning recovery period following night setback might result in increased energy consumption, rather than a savings, is seen to be unfounded.
>
> Selection of a heat pump for residential application is usually based on its cooling capacity rather than its heating capacity. Compensation for inadequate heating capacity can be provided by auxiliary resistance heaters, at some reduction of seasonal

system COP; no compensation is available for inadequate cooling capacity. Excess heating capacity results in a short operating cycle accompanied by some reduction in efficiency. Excess cooling capacity results not only in reduced efficiency, but loss of humidity control as well. A "properly sized" heat pump will, then, have a cooling capacity approximately equal to the maximum hourly cooling load expected. Because the peak cooling loads for comparable houses in different parts of the country are remarkably similar, the heat pump will have excess heating capacity where winters are mild, and insufficient heating capacity where winters are severe.

This excess of heating capacity in mild climates means that the auxiliary resistance heaters will be used more during the defrost cycle (to prevent a flow of chilled air into the house) than for augmenting the heat pump if indoor temperature is held constant. If, following night setback of temperature, rapid recovery is demanded, there will indeed be increased energy consumption by the resistance heaters. This increase is, however, smaller than the decrease in consumption by the compressor, so that there is a substantial net savings of energy.

Where winters are as severe as these experienced by Minneapolis, the heating capacity of the heat pump is expected to be insufficient. The principal use, then, of the auxiliary heaters is to augment the heating capacity of the heat pump, rather than to counter the unpleasant effects of the defrost cycle, whether indoor temperature is held constant or reduced at night. One may then expect reduced consumption by both the compressor and the auxiliary resistance heaters if night setback of indoor temperature is anticipated, and of course, a net reduction of energy consumption for space heating.

Summary and Conclusions from "Savings in Energy Consumption by Residential Heat Pumps: The Effects of Lower Indoor Temperatures and of Night Setback" by R. D. Ellison -1977.

A fixed reduction in room thermostat setpoints has been shown to be a very effective and essentially foolproof means for reducing energy consumption with a residential heat pump system. For the severe northern climate (Minneapolis) chosen for the present study, approximately 8% savings in seasonal input energy (kWh) can be achieved with a typical system for each 1°C setpoint reduction (4% per °F).

Nighttime setback of room thermostat setpoints can also be an effective energy savings method with conventional heat pump heating systems. However, much closer attention to its control is required than for fixed capacity heating systems (gas, oil, or electric forced-air furnaces). In particular:

1. Large Thermostat setback (3°C (5°F) or more) can lead to:
   a. Small seasonal energy savings. Increasing the setback can increase the seasonal energy consumption.
   b. High morning power demand.
   c. Poor indoor comfort during the day.
2. The amount of strip heat used for morning recovery is critical:
   a. Large amount of strip heat can cause a net daily energy loss, particularly if the outdoor air temperature is near the system balance point.
   b. The amount of strip heat chosen must consider:
      1. Indoor comfort during recovery (high capacity is desirable).
      2. Annual energy savings potential (low capacity is desirable).
3. A demand limiting device may be effective in preventing inadvertent energy losses, provided that satisfactory indoor comfort can be maintained.
4. Scheduling is critical:
   a. Night setback is not always energy-effective near the system balance point. This result is aggravated with large supplementary heat availability.
   b. Night setback of only the thermostat second stage (strip heat) would be a compromise measure, providing reasonable nighttime comfort as well as energy savings. By further eliminating nighttime use of strip heat for supply air tempering during defrost, additional energy savings accrue.
   c. The time of set-up, which is followed by a power demand peak, would obviously be affected by the adoption of a day/night electric rate structure. In this case, the recovery period should precede the initiation of day rates.
5. The maximum energy savings achievable by night setback are limited. The peak demands depend on the sizing of the heat pump, strip heat and the

climate. A fixed setpoint reduction, on the other hand, will continue to provide energy savings the more the setpoint is lowered. An alternative to the complexities and shortcomings of night setback would be to keep thermostat setpoints down during the peak heating months (December, January, and February).

Based on the above considerations, we do not recommend the general use of thermostat setback with residential air-source heat pump systems at the present time. The controversy surrounding setback with conventional, fixed-output heating systems is only now beginning to be resolved. Consumer education for the more complex heat pump operating characteristics is similarly only in process. The combination of heat pumps and setback represents a significant advancement in system operational considerations which should be approached cautiously and only as further technical insights are gained concerning the operating characteristics of such systems. The general, unqualified use of setback with heat pumps could lead to a waste of available energy and unnecessary burdens on electric utilities as well as negative consumer reaction. Instead, we recommend the promotion of fixed thermostat setback.

In the near future, we can expect to see new, more sophisticated heat pump controls which will be specifically designed to achieve the maximum energy savings with periodic setback, by integrating all the pertinent data; i.e. indoor and outdoor temperatures, heating load, heat pump capacity, time of day, etc. New heat pump designs will also be offered to the consumer with higher heating capacities at low outdoor temperatures, thus reducing the need for auxiliary heating elements. All of these features will help to insure that periodic thermostat setback with heat pumps will achieve its full savings potential without adding unnecessary complications to this, more complex type heating system.

Conclusions from "Energy Savings Through Thermostat Setback with Residential Heat Pumps" by Dr. Charles E. Bullock, - 1978.

For those systems studied, a thermostat night setback of 10$^{O}$F was effective in reducing energy consumption. Night setback reduced total heating energy requirements, even considering the need for auxiliary electric resistance heating for morning pickup. Actual dollars savings will be dependent on current and future rate design.

Depending on the location and control scheme used, reduction in energy consumption ranged from 5.5% to 20% with night setback of a two-stage thermostat. Based on a more detailed analysis of setback variations in Minneapolis and St. Louis, it appears that a $5^{o}F$ or $6^{o}F$ setback can save nearly as much energy as a $10^{o}F$ setback, with a reduced peak demand and faster pickup recovery. This results from the fact that less auxiliary heat is required during the pickup period. Recent work by another investigator indicates that there are some conditions under which setback savings are actually reduced if the setback magnitude exceeds an optimum amount.

This study has considered night setback in a specific typical residence. Future studies will investigate how night setback savings are affected by variations in the thermal heat storage capacity of the house, by the amount of insulation, and by infiltration characteristics. Clearly the relative heating capacities of the heat pump and the auxiliary heating elements will affect night setback savings, and further investigation will also consider systems sized with a range of balance points.

In the future, demand or "time-of day" electrical metering is likely to become more widespread. Guidelines must be developed to give the consumer an indication of the contribution of night setback in reducing the cost of heat pump system operation under possible future rate structures. The heat pump controls of the future will therefore likely be of a sophisticated nature, utilizing weather, time, structural characteristics, and energy cost data to minimize the cost of operation. Also, it is expected that thermal storage technology may play a significant role in limiting utility peak demand periods. Conclusions from "Saving Energy by Night Setback of a Residential Heat Pump System" by G. R. Schade - 1978.

## MARKET SURVEY

### Method

The market survey was intended to identify manufacturers of appropriate heat pumps and controls suited for setback purposes. Performance data and benefits of these units were desired. Safety, legal, and code requirements relating to residential and light commercial heat pump systems were also desired. The following actions were taken to achieve the objectives of the market survey:

- Letter to manufacturers
- Interviews with Manufacturers

Survey of Manufacturers

The letter sent to the various manufacturers is reproduced on the following page. The source of manufacturers solicited was the Thomas Register and all firms listed under heat pumps, heat pump controls, and heat control thermostats were solicited. The American Refrigeration Institute Directory was also used. Approximately 95 inquiries were mailed and the responses numbered 11. The firms contacted are listed after the reproduced letter. The replies were catalogued according to their applicability.

Johns-Manville
Sales Corporation

Research & Development Center

Ken Caryl Ranch
Denver, Colorado 80217
(303) 979-1000

July 28, 1980

Dear Sir:

Johns-Manville Research and Development Center has been engaged to study the potential energy conservation achievable by night set-back of air-to-air, unitary heat pumps. Our client seeks information about the benefits or penalties of night set-back in accordance with DoE requirements mandated in the July 1979 Federal Register. Residential heat pumps of both prior and current design are to be considered. Some specific questions which come to mind include the following.

- What is the effectiveness of temperature set-back in the seven DoE climatic regions?

  Ex. Night set-back in residences and night and weekend set-back in small commercial buildings.

- Is there a minimum elapsed time of set-back required to achieve energy savings as a function of ambient air temperature? What about minimum or maximum degrees of temperature set-back?

- What added control devices and system modifications are needed to achieve a set-back and restart schedule to minimize energy use? What is the availability and cost of these devices?

Your firm's position suggests that you are well qualified to contribute to our survey. Your experience should be helpful in resolving some of the apparent contradictions in the technical literature. Your contribution to our survey should prove to be beneficial in achieving significant energy conservation; or, possibly, avoiding significant increases in energy consumption.

It is likely that our client will release our final report as public information and all those who contribute to the study will be properly acknowledged. May I hear from you soon?

Yours truly,

P B Shepherd

P. B. Shepherd
Sr. Research Associate

AC Manufacturing Co.
Old Cuthbert and Deer Roads
Cherry Hill, NJ 08000

AC Manufacturing Co.
Old Cuthbert and Deer Roads
Cherry Hill, NJ 08000

Addison Products Co.
Addison, MI 49220

Advance Design Associates, Inc.
Temp Master Systems
Orlando, FL 32800

Amana Refrigeration, Inc.
Amana, Iowa 52203

American Air Filter Co. Inc.
200 Central Avenue
Louisville, KY 47744

Armor Electric Inc.
Erie, PA 16500

Bard Manufacturing Co.
Box 607
Bryan, OH 43506

Barkow Manufacturing Co. Inc.
2230 S. 43rd
Milwaukee, WI 53200

Bryant Air Conditioning/BDP Company
7310-T W. Morris
Indianapolis, IN 46200

Budco
Bloomfield, CT 06002

Carrier A/C Group
Carrier Corp.
Carrier Pkwy.
Syracuse, NY 13200

Century By Heat Controller, Inc.
1900 Wellworth at Losey
Jackson, MI 49200

Day and Night/Bryant/Payne Brands/BDP Co.
7310-T W. Morris
Indianapolis, IN 46200

Dunham-Bush Inc.
178 South St.
West Hartford, CT 06100

Dunham-Bush Inc.
Residential and Light Commercial Products
Harrisburg, VA 22801

Elm Brook Refrigeration, Inc.
21000 Enterprise Avenue
Brookfield, WI 53005

Fasco Industries, Inc.
Consumer Products Division
810 Gillespie St.
Fayetteville, NC 28302

Fedders Corp.
Edison, NJ 08117

Florida Heat Pump Corp.
610 S.W. R Avenue
Pompano Beach, FL 33000

Fraser and Johnston Co.
San Lorenzo, CA 94580

Friedrich Air Conditioning and Refrigeration Co.
N. Pan Am Expressway
San Antonio, TX 78200

General Electric Co.
Central Air Conditioning
Appliance Park
Louisville, KY 40200

Gaffers and Sattler
Los Angeles, CA

Heat Controller Inc.
8100 N. Monticello Avenue
Jackson, MI 39200

Heat-Exchangers Inc.
8100 N. Monticello Avenue
Skokie, IL 60076

Heil-Quaker Corp.
647 Thompson Lane
Nashville, TN 37200

Infortran, Inc.
New York, NY

International Heating and Air Conditioning
Division of Neil McLain Co. Inc.
Barber and Park Avenue
Utica, NY 13500

Johnson Corp.
851 W. Third Avenue
Columbine, OH 43200

Koldware Div. of Heat Exchangers Inc.
8100 N. Monticello Avenue
Skokie, IL 60076

Lennox Industries Inc.
Marshaltown, Iowa 50158

Luxaire Inc.
West of Filbert
Elyria, OH 44000

Mammoth Div. of Lean Siegler Inc.
13120-B County Road Six
Minneapolis, Minn. 55400

Marvair Co.
P.O. Box 400
Cordele, GA 31015

McGraw Edison Co.
Air Comfort Division
706 North Clark
Albion, MI 49224

McMillan Heat Pumps Inc.
P.O. Box 5897
Jacksonville, FL 32200

Mueller Climatrol Corp.
Piscataway, NJ 08854

Modern Comfort Inc.
2250 Dwenger Avenue
Ft. Wayne, IN 46800

Northrup Inc.
Hutchins, TX 75141

Patco Inc.
Pennsauken, NJ 08110

Phelps-Dodge Brass Co./Lee Brothers
Anniston, Ala. 36200

Royal Air Conditioning Co.
1035 E. 26th St.
Hialeah, FL 33000

Research Engineering Mfg. Co.
Phoenix, AZ 85000

Rheem Manufacturing Co.
Air Conditioning Division
Fort Smith, Ark. 72900

Ruud Air-Conditioning Division
City Investing Co.
Fort Smith, Ark. 72900

Singer Co.
The Climate Control Division
Cartaret, NJ 07008

Solar Kinetic Inc.
Mechanicsburg, OH 43033

Sun Dial Solar Heat and Air Conditioning
Square D Company
Mesquite, TX 75100

Solus
Houston, TX 77000

Southwest Manufacturing Division of McNeil Corp.
10 North Elliott
Aurora, MO 65605

Sunsau
Tewksburg, MA 01876

Supreme Air
Santa Fe Springs, CA 90670

Vanguard Energy Systems
San Diego, CA 92100

Vilter Mfg. Corp.
2223 South First St.
Milwaukee, WI 53200

Tappan Air Conditioning Division
Elyria, OH 44000

Thermo-Products Inc.
North Judson, IN 46366

Weatherking, Inc.
P.O. Box 20434
Orlando, FL 32800

The Williamson Co.
Cincinnatti, OH 45200

Wormser Scientific Corp.
Stamford, CT 06900

Wesco Air Comfort Division
Wesco-Moore Clear Inc.
Beavertown, OR 97005

Westinghouse Electric Corp.
Central Residential A/C Division
Normann, OK 73000

Whirlpool Heating and Cooling Products
Nashville, TN 37200

York Division
Borge Warner Corp.
South Richland Avenue
York, PA 17400

Emerson Quiet Kool Div.
St. George and Woodlime Avenue
Woodbridge, NJ 07095

Antar Industries Inc.
350 5th Avenue
New York, NY 10001

Trane Co.
3600 Thomas Creek Road
La Crosse, WI 54601

Payne Air Conditioning Co.
855 Anaheim-Puente Rd.
City of Industry, CA 91744

Bohn Aluminum and Brass Division
Gulf & Western Manufacturing Co.
23100 T. Providence Drive
Southfield, MI 48037

Airtemp Corporation
Woodbridge Avenue
Addison, Michigan 49220

Armstrong Furnace Company
A Subsidiary of Magic Chef, Inc.
851 West Third Avenue
Columbus, Ohio 43212

Climatrol Sales Company
Woodbridge Avenue
Edison, New Jersey 08817

The Coleman Company, Inc.,
250 North Street
Francis Street
Wichita, Kansas 67201

Crane Supply Company
300 Park Avenue
New York, New York 10022

Day & Night Air Conditioning
855 Anaheim-Puente Road
La Puente, California 91749

Duo-Therm
Division of Motor Wheel Corporation
509 South Poplar Steet
LaGrange, Indiana 46761

Frigiking Tappan, SJC Corp.
206 Woodford Avenue
Elyria, Ohio 44036

Goettl Air Conditioning, Inc.
2005 East Indian School Road
Phoenix, Arizona 85016

The Heil-Quaker Corporation
647 Thompson Lane
Nashville, Tennessee 37204

The Henry Furnace Company
Post Office Box 4022
Elyria, Ohio 44036

Janitrol, SJC Corp.
206 Woodford Avenue
Elyria, Ohio 44036

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A Subsidiary of Magic Chef, Inc.
851 West Third Avenue
Columbus, Ohio 43212

Lowe's Company, Inc.
Box 1111
North Wilkesboro, North Carolina 28659

Magic Chef, Inc.
851 West Third Avenue
Columbus, Ohio 43212

McDonald Mfg., Co., A.Y.
Post Office Box 508
Dubuque, Iowa 52003

Montgomery Ward & Co., Inc.
P. O. Box 8339
Chicago, Illinois 60680

Sears, Roebuck and Co.
Sears Tower
Chicago, Illinois 60684

Spartan Electric Company
P. O. Box 150
Fayetteville, North Carolina 28302

The Square D Company
P. O. Box 766
Mesquite, Texas 75149

Westinghouse Electric Corp.
Staunton Operation
Heating & Cooling Business Unit
P. O. Box 2510
Staunton, Virginia 24401

The Williamson Co.
3500 Madison Road
Cincinnati, Ohio 45209

John Zink Company
P. O. Box 7388
Tulsa, Oklahoma 74105

NOT DELIVERABLE AS ADDRESSED:

McMillan Heat Pumps, Inc.
P. O. Box 5897
Jacksonville, FL 32200

Royal Air Conditioning Co.
1035 E. 26th Street
Hialeah, FL 33000

Supreme Air
Santa Fe Springs, CA 90670

Research Engineering Mfg., Co.
Phoenix, AZ 85000

Patco, Inc.
Pennsauken, NJ 08110

Mueller Climatrol Corp.
Discataway, NJ 08854

Sunsau
Tewksburg, MA 01876

Vanguard Energy Systems
San Diego, CA 92100

Advance Design Associates, Inc.
Temp. Master Systems
Orlando, FL 32800

RESPONDENTS WITH PREVIOUSLY ESTABLISHED COMPUTER MODELS REGARDING HEAT PUMP SETBACK:

Carrier Corp.
Research Division
Carrier Parkway
Syracuse, NY 13221

Trane Air Conditioning
LaCrosse, WI 54601

RESPONDENTS SUPPLYING VALUABLE INFORMATION BASED ON PAPERS EXTERNAL TO THEIR COMPANY:

Borg Warner Corp.
York Division - Unitary Products
P. O. Box 1592
York, Penn. 17405

Singer
Climate Control Division
Cartaret, NJ 07008

City Investing Co.
Rheem Air Conditioning Division
5600 Old Greenwood Road
Fort Smith, AK 72903

Electric Power Research Institute
3412 Hillview Avenue
P. O. Box 10412
Palo Alto, CA 94303

RESPONDENTS WITH REFERRALS TO ANOTHER SOURCE:

Sears, Roebuck and Co.
925 S. Homan Avenue
Chicago, IL 60607

Friedrich Air Conditioning & Refrigeration Co.
4200 N. Pan Am Expressway
P. O. Box 1540
San Antonio, TX 78295

Bard Manufacturing Co.
P. O. Box 607
Bryan Ohio 43506

Thermo Products, Inc.
P. O. Box 217
North Judson, Ind. 46366

Heat Controller, Inc.
Losey at Wellworth
Jackson, Michigan 49203

## COMPUTER SIMULATION STUDIES

The dynamic computer model has become an integral part of the analysis of heating systems. The calculations of hourly heating loads based on building size, occupancy and infiltration characteristics are inherently less tedious. And field data has proven that, in general, dynamic models are more accurate than the conventional bin methods.[18] This practice of using dynamic computer simulation models becomes very appropriate for heat pump systems. In addition to calculating heating load, the capacity of the heat pump may also be determined. This is important because of the dependency of heat pumps on changing outdoor temperatures.

The basics of the models can be understood by reviewing the work of the Carrier Corp., done in 1978. The excerpt which follows does not include specific equations; their inclusion is not as important as the basic philosophy of the model. The paper was written by Dr. Charles Bullock of Carrier Corp. and is entitled "Energy Savings Through Thermostat Setback with Residential Heat Pumps". It appeared in the ASHRAE Journal in September 1978 under the title of "Thermostat Setbacks and Residential Heat Pumps".

<u>Simulation Model</u>

> The present study was conducted using a detailed digital computer simulation program which predicts the true dynamic or cycle-by-cycle performance of an actual heat pump when applied to a particular combination of residential structure, controls and weather (temperature, solar radiation, wind speed). Details of the simulation model have been published and will not be repeated here. In operation, the program determines the instantaneous space heating load at a given point in time, accounting for all modes of heat transfer through the structure as well as for thermal storage effects. The equipment instantaneous heating capacity is then calculated and compared with the heating load -- a discrepancy leads to a temporary change in the occupied space temperature. The space temperature is sensed by the thermostat which, in turn, makes appropriate adjustments to the equipment performance. Changes in the space temperature also affect the instantaneous heating load.
>
> The simulation model thus accounts for the interactive and feedback effects which occur in a real-life heat pump installation. The computation

procedure is repeated for each time step in the period of interest, using sufficiently small time steps (30 seconds, typically) to insure accuracy of the results. Although the system model can be used simply to determine equipment operating hours and energy consumption for various operating conditions, it also yields information about the transient performance of the system, including the number of compressor cycles, strip heat cycles, and room temperature cycles. Variation in control strategies, such as thermostat setback, is also simple to investigate with a cycle-by-cycle simulation, but may be impossible with a simpler procedure such as a "bin" method.

The simulation models for the structure controls and equipment utilized in this study have been verified and refined through the use of extensive laboratory testing as well as field data from fully-instrumented residential heat pump systems in Boston, Syracuse, Minneapolis, and Seattle. The heat pump systems in Syracuse and Seattle, in particular, have recently initiated experimental thermostat night setback programs. These installations were monitored during the current heating season to provide actual field data which will be used to qualify the results presented in the present paper.

The present study is based on the Minneapolis test house whose key features are shown in Table I. Minneapolis was chosen for the present study because of the large number of hours of low outdoor temperatures which would accentuate any effects due to low temperatures. A key factor in the results is the amount of auxiliary strip heat used with the heat pump. The strip heat capacity shown (17 kW, in two 8.5 kW stages) is that needed to satisfy the design heating load. An outdoor thermostat, set at $-3.9^{o}C$ ($25^{o}F$) was used to control one of the strip heat stages.

The base system simulation had thermostat setpoints as follows:

1st stage (heat pump): $21.1^{o}C$ ($70^{o}F$)
2nd stage (strip heat): $20.0^{o}C$ ($68^{o}F$)

The base simulation also initiated automatic defrost cycles at fixed increments of compressor run time (90 minutes) during which there was automatic tempering of the circulating air by one or both strip heat elements.

The preceding model was one which was used as a data base in our study. The others are the Honeywell study - written by George Schade, entitled "Saving Energy by Night

Setback of a Residential Heat Pump System", and the ORNL study - written by R. D. Ellison, entitled "Savings in Energy Consumption by Residential Heat Pumps: The Effects of Lower Indoor Temperatures and of Night Setback." Three studies were used for several reasons. First, three different opinions and corresponding results, were presented by the three authors. It was not the scope of this study to determine the most accurate or to develop our own simulation model. It should be noted, though, that several manufacturers are currently engaged in developing new data; computer models and further research by neutral agencies is both appropriate and needed. The second reason for using three studies was to obtain a more diverse data base on which to calculate life cycle economics. In addition, it was felt that these studies provided the most realistic results on which heat pump setback could be reported. Refer to the following table for comparative data regarding the three studies.

## ECONOMIC AND ENERGY CONSIDERATIONS OF NIGHT SETBACK

The decision to implement an alternative system, of any type, has invariably been based on cost. The economics of the alternative are examined and the determination made.

Recently, the rapid acceleration of energy prices has created several interesting alternatives to conventional policies. The shortage of non-renewable fossil fuels sometimes makes the decision an energy-based one rather than a cost-based decision. Local availability and national surplus are two considerations important to this philosophy. Also, as energy prices continue to accelerate, conservation alternatives become increasingly more attractive.

Depending on geographical location and priorities, the facilities engineer must decide whether the decision to setback will be based on cost savings or energy savings. This report does not attempt to establish the order of priority of these factors.

Our results show that the cost savings which can be expected are greater in certain regions of the country - primarily colder climate regions. Other factors which effect savings potential are electricity cost and initial cost. When initial cost (of alternative system) increases, savings potential decreases. When electricity cost increases, savings potential increases. This is very important. Appendix B

TABLE 1

| | Carrier | Honeywell | ORNL |
|---|---|---|---|
| Number of Locations Investigated | 1 | 8 | 6 |
| Area of Structure ($ft^2$) | 1,900 | 900 | 1,500 |
| Daily Internal Heat Generated | Total = 78,375 | | |
| Nightime Occupancy | BTU/Day | 900 BTU/h | 2.33 People/Hr. |
| Daytime Occupancy | Varies | 450 BTU/h | 2.33 People/Hr. |
| Lights & Appliance | Hourly | 5,450 BTU/h | 17.01 KW/Hr. |
| Type of Simulation | Digital Computer | Hybrid Computer | Modified NBSLD Program |
| Weather Intervals | Hourly | Hourly | Hourly |
| Heat Pump Size (Tons) | 3 | 2 | 3-1/2 |
| Electric Resistance Heat (KW) | 10, 17 (2 stages) | Sized to Meet Daytime Heating Load | 18 |
| Structure Characteristics<br>Walls (Insulation)<br>Ceiling (Insulation) | <br>5 Inches<br>12 Inches | <br>3-5/8 Inches<br>6-1/2 Inches | <br>1-7/8 Inches Fiberglass<br>3 Inches Fiberglass |
| Windows (Area) | 250 $ft^2$ | 99 $ft^2$ | 86.3 $ft^2$ |
| Heat Transfer Modes Accounted For | Radiation, Convection, Conduction | Radiation, Convection, Conduction | Radiation, Conduction |
| Heating Load Computation Interval | 30 Sec. Typical Averages Hourly | Hourly | Hourly |
| Control Scheme Employed | 4°F Setback, 17 KW<br>10°F Setback, 10 KW<br>4°F Setback, 17 KW<br>4°F Setback, 10 KW 2 Stage Thermostat | 2 Stage, 2 Outdoor<br>2 Stage, 1 Outdoor<br>2 Stage, No Outdoor<br>10°F Night Setback | 72°F Continuous<br>68°F Continuous<br>68°F Set/8°F Setback<br>68°F Set/13°F Setback 2 Stage Indoor Thermostat with Outdoor Thermostats |

shows life cycle data.

Refer to DOE Region 1 - Boston. The electricity cost is \$.06/kWh. For a 1.5 ton system with two outside thermostats, the alternative setback system employs 10°F of setback. The accompanying energy savings and cost savings are 11.7% and 5.8%, respectively. Now refer to DOE Region 8 - Denver. The electricity cost is \$.036/kWh. The energy savings and cost savings are 13.5% and 5.1%, respectively. Note that in Boston, where the electricity is more expensive, the cost savings potential is greater. This example also illustrates another important point. The heat pumps are exact in size. The setback is 10°F in both cases. The control scheme is exact and the average winter temperatures are very similar. Yet the energy savings are predicted at 13.5% for Denver and only 11.7% for Boston. The base annual fuel cost is \$352 for Boston and only \$212 for Denver. What caused such a large difference in percent energy savings and cost for such similar systems?

1. The respective electricity rates. If the consumption in Boston was figured with a Denver electricity rate, the bill would be \$211.20.
2. The energy consumption savings difference can be explained by remembering the weather data was read hourly. Denver commonly has a very cold morning temperature followed by a series of warmer temperatures throughout the day and evening. This causes the average winter temperature to appear low and is a good reason for calculating consumption on an hourly basis. By reviewing the remaining analyses in Appendix B, it is apparent that energy savings percent is greater when the climate is warmest. This is what happened in the example of Boston and Denver.

The data in Appendix A reveals several conclusions regarding economics and energy considerations of night setback of heat pumps:

1. Energy savings, in percent, are greatest in warm climates.
2. Energy savings, in consumption, are greatest in cold climates.
3. Cost savings are increased when electricity price is increased.
4. Cost savings may be negligible even if energy savings are achievable.

The facilities engineer should refer to the Recommendations section of this report for guidance on practical applications.

## MARKET CONSIDERATIONS

The purpose of this section is to explore the market acceptance of heat pumps and sophisticated controls. Conclusions will be drawn regarding the acceptance and applicability of these items.

### Heat Pump Market Acceptance

The history of the acceptance of the heat pump is well documented. The Gordian report - "Evaluation of the Air-to-Air Heat Pump for Residential Space Conditioning" - as well as numerous other documents report market acceptance as poor. Twenty five to thirty years ago the market was very poor due to poor reliability. However, as reliability improved and energy prices continued to rise steadily, the sales of heat pumps grew immensely. The Gordian report, which was issued in 1976, concluded that heat pumps offered an attractive alternative to oil fired systems in northern climates. However, they would not be popularly accepted until gas became excessively expensive or unavailable. Several tables taken from the Gordian report have been included in this section. Table 2 is a reference table to obtain depreciation periods of various heating and cooling systems. The heat pump has the shortest depreciation period. Since 1976, this figure of 9 years has not changed significantly. Our survey of dealers indicated an average depreciation period of 10 years. Table 3 shows the 1975 rates for electricity, natural gas, and fuel oil. The annual operating and energy costs are presented in Table 4 and Table 5. In 1976, it was more expensive to own a heat pump than a gas furnace in every city except Seattle, where electricity rates were very low. This is still true today. According to almost 100% of dealers surveyed, a gas furnace is less expensive in every location except where gas is unavailable or electricity is exceedingly inexpensive. The same dealers recommended against the use of heat pumps, even their own. Table 6, from the Gordian report, relates the needed increase in gas price to make the heat pump cost competitive. Implicit in this estimate is that the price of electricity is not allowed to increase. The Federal Register, Part IV, reports the prices (1980) of fuels. By comparing the prices in 1980 to those in 1975 given in Table 3, and then comparing the increases to those given in Table 6, several interesting conclusions result:

1. The percent increase of gas price was not great enough in any DOE region to make heat pumps cost competitive.

TABLE 2

DEPRECIATION PERIOD OF HEATING AND COOLING SYSTEMS

| Component | Capital Recovery Factor (at 9% Interest) | Depreciation Period (Years) |
|---|---|---|
| Heat Pump | 0.1668 | 9[a] |
| Central Air Conditioner | 0.1560 | 10[b] |
| Gas Furnace | 0.1203 | 16[b] |
| Oil Furnace | 0.1560 | 10[b] |
| Oil Tank | 0.1095 | 20[b] |
| Electric Warm Air Furnace | 0.1240 | 15[b] |
| Electric Baseboard Heaters | 0.0929 | 40[b] |
| Room Air Conditioners | 0.1560 | 10[b] |
| Ductwork, Chimney | 0.0929 | 40[c] |

Sources:

a. Industry spokesmen give the life as 8-10 years.

b. ASHRAE Handbook and Product Directory, 1973 Systems (11)

c. Internal Revenue Service

TABLE 3

AUGUST 1975, EFFECTIVE AVERAGE RATES FOR HEATING: ELECTRICITY, NATURAL GAS, and FUEL OIL

| City | Electricity (Per KWH) | Natural Gas (Per Therm) | Number 2 Fuel Oil (Per Gallon) |
|---|---|---|---|
| | Average Energy Cost, Dollars | | |
| Houston | 0.016 | 0.140 | 0.310[d] |
| Birmingham | 0.022 | 0.133 | 0.370 |
| Atlanta | 0.019 | 0.126 | 0.350 |
| Tulsa | 0.016 | 0.123 | 0.310 |
| Philadelphia | 0.025[a] 0.043[b] | 0.217 | 0.389 |
| Seattle | 0.009[c] | 0.247 | 0.396 |
| Columbus | 0.026[c] | 0.146 | 0.378 |
| Cleveland | 0.026 | 0.128 | 0.378 |
| Concord | 0.032 | 0.203 | 0.409 |
| U. S. Average | 0.038 | 0.152[f] | 0.391[f] |

Sources: See Appendix B.

a All Electric October to May
b All electric Except October to May
c All Electric
d Rate for Tulsa, Okla.
e Cordian Associates (5)
f U.S. Bureau of Labor Statistics (13). Not an average of tabulated prices.

TABLE 4

ANNUAL OWNING AND OPERATING COSTS FOR ALTERNATIVE RESIDENTIAL SPACE CONDITIONING SYSTEMS (LOCAL TARIFFS - AUGUST 1975) (Dollars)

| City | Heat Pump | Gas Furnace and Central Air Conditioning | Electric Furnace and Central Air Conditioning | Oil Furnace and Central Air Conditioning | Baseboard Resistance Heaters and Room* Air Conditioning |
|---|---|---|---|---|---|
| Houston | 688.80 | 544.80 | 574.04 | 685.72 | 410.21 |
| Birmingham | 637.66 | 572.54 | 684.88 | 767.00 | 499.72 |
| Atlanta | 700.78 | 560.57 | 656.74 | 743.77 | 482.98 |
| Tulsa | 744.42 | 598.23 | 735.74 | 811.59 | 538.89 |
| Philadelphia | 885.89 | 743.09 | 944.61 | 935.28 | 728.23 |
| Seattle | 477.29 | 518.30 | 473.23 | 684.70 | 312.83 |
| Columbus | 876.61 | 701.70 | 946.10 | 964.60 | 757.86 |
| Cleveland | 943.29 | 637.59 | 1071.75 | 954.83 | 823.81 |
| Concord | 1044.92 | 667.69 | 1219.93 | 928.32 | 1024.90 |

* Individual room cooling equivalent to 57-89% of full cooling load.

# TABLE 5

ANNUAL ENERGY COST OF COMPETITIVE SPACE CONDITIONING SYSTEMS
(LOCAL TARIFFS - AUGUST 1975)

| CITIES | | ANNUAL COST, DOLLARS | | | | |
|---|---|---|---|---|---|---|
| | | HEAT PUMP | GAS FURNACE AND CENTRAL AIR CONDITIONER | ELECTRIC FURNACE AND CENTRAL AIR CONDITIONER | BASEBOARD RESISTANCE HEATERS AND WALL AIR CONDITIONERS | OIL FURNACE AND CENTRAL AIR CONDITIONERS |
| Houston | Total Annual | 210.58 | 187.99 | 216.43 | 145.95 | 206.84 |
| | Total Heating Season | 22.45 | 25.69 | 53.90 | 48.47 | 44.31 |
| | Total Cooling Season | 188.13 | 162.53 | 162.53 | 97.48 | 162.53 |
| Birmingham | Total Annual | 237.45 | 213.69 | 324.46 | 274.90 | 275.91 |
| | Total Heating Season | 87.02 | 61.61 | 174.44 | 160.97 | 125.89 |
| | Total Cooling Season | 150.43 | 152.08 | 150.02 | 113.93 | 150.02 |
| Atlanta | Total Annual | 249.40 | 208.62 | 304.21 | 261.03 | 271.38 |
| | Total Heating Season | 77.02 | 58.88 | 154.97 | 143.42 | 121.64 |
| | Total Cooling Season | 172.38 | 149.74 | 149.24 | 117.61 | 149.74 |
| Tulsa | Total Annual | 249.77 | 209.75 | 349.11 | 315.27 | 293.72 |
| | Total Heating Season | 124.37 | 94.08 | 233.44 | 217.26 | 178.05 |
| | Total Cooling Season | 125.40 | 115.67 | 115.67 | 98.01 | 115.67 |
| Philadelphia[a] | Total Annual | 402.98 | 368.90 | 569.28 | 490.59 | 434.41 |
| | Total Heating Season | 200.40 | 186.96 | 393.32 | 355.88 | 252.47 |
| | Total Cooling Season | 202.58 | 181.94 | 175.96 | 134.71 | 181.94 |
| Seattle[a] | Total Annual | 85.94 | 205.01 | 160.04 | 124.97 | 247.37 |
| | Total Heating Season | 70.55 | 192.37 | 148.43 | 115.04 | 234.73 |
| | Total Cooling Season | 15.39 | 12.64 | 11.61 | 9.93 | 12.64 |
| Columbus[a] | Total Annual | 383.22 | 277.33 | 582.64 | 528.66 | 419.67 |
| | Total Heating Season | 280.58 | 159.34 | 495.94 | 453.99 | 301.68 |
| | Total Cooling Season | 102.64 | 117.99 | 86.70 | 74.67 | 117.99 |
| Cleveland | Total Annual | 444.54 | 252.40 | 664.48 | 598.85 | 441.11 |
| | Total Heating Season | 345.04 | 164.03 | 576.11 | 539.19 | 352.74 |
| | Total Cooling Season | 99.50 | 88.37 | 88.37 | 59.66 | 88.37 |
| Concord | Total Annual | 594.21 | 338.73 | 892.03 | 794.07 | 482.02 |
| | Total Heating Season | 532.18 | 280.71 | 834.01 | 761.14 | 424.00 |
| | Total Cooling Season | 62.03 | 58.02 | 58.02 | 32.93 | 58.02 |

a) All electric rate.

TABLE 6

INCREASE OR DECREASE IN GAS OR OIL PRICE
TO MAKE HEAT PUMP COST-COMPETITIVE
WITH FOSSIL FUEL SYSTEMS
(Local Tariffs - August 1975)

| City | Per Cent Increase (Decrease) in Unit Price[a] Gas | Oil |
|---|---|---|
| Houston | 485 | (36) |
| Birmingham | 219 | (59) |
| Atlanta | 254 | (36) |
| Tulsa | 162 | (41) |
| Philadelphia | 84 | (18) |
| Seattle | (29) | (89) |
| Columbus | 165 | (2) |
| Cleveland | 207 | 6 |
| Concord | 143 | 35 |

[a] A decrease means that the heat pump is the better investment at current prices.

TABLE 7

INCREASE OR DECREASE IN EFFECTIVE ANNUAL ELECTRICITY PRICE FOR ELECTRIC RESISTANCE SYSTEMS NEEDED TO MAKE THE HEAT PUMP COST-COMPETITIVE WITH THEM
(Local Tariffs - August 1975)

| City | Per Cent Increase or (Decrease)[a] in Unit Price: Electric Furnace and Central Air Conditioning | Per Cent Increase or (Decrease)[a] in Unit Price: Baseboard Heat and Room Air Conditioning |
|---|---|---|
| Houston | 657 | 463 |
| Birmingham | 36 | 754 |
| Atlanta | 25 | 475 |
| Tulsa | 6 | 205 |
| Philadelphia | (55) | 45 |
| Seattle | 33 | 400 |
| Columbus | (34) | 80 |
| Cleveland | (63) | 41 |
| Concord | (59) | 9 |

[a] A decrease means the heat pump is the better investment at current prices.

TABLE 8

ANNUAL OWNING AND OPERATING COSTS FOR ALTERNATIVE RESIDENTIAL SPACE CONDITIONING SYSTEMS - U.S. AVERAGE FUEL PRICES, AUGUST, 1975

| City | Heat Pump[a] | Gas Furnace and[b] Central Air Cond. | Electric Furnace and[a] Central Air Cond. | Oil Furnace and[c] Central Air Cond. | Baseboard Resistance Heaters[a] and Room Air Cond.[d] |
|---|---|---|---|---|---|
| Houston | 848.87 | 685.83 | 759.50 | 834.00 | 536.31 |
| Birmingham | 829.78 | 648.49 | 816.86 | 851.52 | 614.85 |
| Atlanta | 803.97 | 628.80 | 806.81 | 814.23 | 608.65 |
| Tulsa | 901.66 | 669.84 | 981.24 | 916.24 | 755.97 |
| Philadelphia | 877.95 | 638.60 | 981.63 | 884.04 | 777.87 |
| Seattle | 685.45 | 489.53 | 795.79 | 726.19 | 641.88 |
| Columbus | 936.36 | 646.83 | 1062.23 | 898.31 | 861.18 |
| Cleveland | 1007.72 | 671.75 | 1167.82 | 946.19 | 946.70 |
| Concord | 1022.28 | 609.00 | 1177.72 | 899.96 | 982.95 |

[a] Electricity price per kilowatt hour:
$0.03 heating season
$0.0375 cooling season
[b] Gas price per therm: $0.1518
[c] Oil price per gallon: $0.3911
[d] The room air conditioners account for from 57% to 89% of the cooling demand of the house in the various cities. See the text for the actual coverage.

2. The increase of electricity price in Seattle made the use of heat pumps there uneconomical according to the figures given in the Gordian report.
3. The national average increase in gas price, related to increase in electricity, was about 120%. It would have needed to be about 190% to make heat pumps cost competitive.

Market Acceptance of Sophisticated Controls

The general market acceptance of microcomputer controls is very good. The recent ASHRAE convention in Chicago (January 1980) was dominated by control manufacturers' demonstrations. Many companies presently produce and actively advertise microcomputer controls. This is not necessarily the case for heat pump controls. Several sophisticated controls currently manufactured are adaptable to heat pumps. Yet their acceptance is not popular, possibly because many heat pump manufacturers recommend against the use of night setback. During the course of numerous conversations with manufacturers and dealers of heat pumps, a large percentage indicated that the use of sophisticated controls is unnecessary. This leads to the conclusion that market acceptance of sophisticated controls, microcomputer or otherwise, <u>for use with heat pumps</u> is currently poor.

We feel that the popular acceptance of microcomputer controls could be realized by:

1. Obtaining more conclusive data on the benefits of night setback.
2. Relating the potential energy savings to the customer according to the geographical location.
3. Reducing the installed price of the controls to a cost effective level.

In short, controls designed specifically for night setback of heat pumps are not popular. More research is required to determine their true benefits. Until this research is complete, the facilities engineer will find it difficult to locate a control system to meet the needs of the facility.

## HEAT PUMP CONTROLS

It is becoming increasingly evident that energy conservation by heat pump thermostat setback will be accomplished primarily by the use of newly developed controls. The complexities involved with the reliable operation of heat pump systems can no longer be handled efficiently with conventional controls when setback is integrated into the system. This does not mean that the controls presently on a heat pump must be replaced. Energy conservation is possible in certain regions with the prudent selection of setback scheme. However, energy conservation will be increased if the thermostat is microcomputer controlled.

The purpose of this section is to discuss basic control strategies, sophisticated control strategies, cost justification of these new controls and manufacturers currently engaged in developing these controls.

## Basic Control Strategies

The control system should be designed to provide flexible and effective heat pump operation.[19] Capacity modulation, heating to cooling selection, and automatic defrosting should be provided. The control system should prevent the use of electric resistance heat until 1) the heat pump system is unable to satisfy the heating requirements at full capacity; 2) the outdoor air is below a predetermined outdoor temperature. Several methods of system changeover commonly used are:

1. A conditioned space thermostat
2. An outdoor air thermostat
3. Manual changeover
4. A sensing device which responds to greater load requirements

Typically, a control system consists of a two stage thermostat. One stage is set inside for the desired temperature. The other stage is set outside. Normally the setting is around the heat pump balance point - the temperature at which the compressor can no longer satisfy the heating load by itself. When the outdoor temperature drops below the setting, supplemental electric resistance heating is the result. Additional problems occur with heat pump systems. The most devastating problem relating to controls is defrost. Reports indicate that with typical demand-type defrost controls about 8-10% of the annual energy consumption is due to defrost. Loss of refrigerant, compressor failure, and temperature sensing are other problems which typically need control but rarely are included in conventional control schemes.

## Sophisticated Control Strategies

Our studies indicate that Honeywell and several other manufacturers are currently developing sophisticated controls to insure effective night setback. The mechanics of these controls is not known. However, one thing is certain: Their initial cost must be low enough to justify the purchase.

This is, no doubt, one of the major problems confronting the design engineers.

The controls of the future will be microcomputers. They will be able to perform new and improved control functions by solving difficult system problems. In September of 1980 in the ASHRAE Journal, Bonne and Mueller of Honeywell, Inc. indicated in their paper, "Heat Pump Controls: Microelectronic Technology", that the 11 major control priorities are, in order of priority:

1. Improved Defrost
2. Loss of Refrigerant Protection
3. Compressor Fault Detection/Indication
4. Field Diagnostic Package
5. Minimum Off Timer
6. Crankcase Low Temperature Interlock
7. Automatic Auxiliary Heat
8. High Discharge Temperature Protection
9. High Discharge Pressure Protection
10. Inadequate Indoor Air Flow Protection
11. Automatic Emergency Heat

The paper discusses the unique abilities of the microcomputer to accept messages from sensors, interpret them, and eliminate the problem or warn the customer. The major benefit of such a system would be to detect problems before they occur and, therefore, save the customer money on maintenance. In addition, it would efficiently control defrost and other problems which increase energy consumption.

This control system is one which employs a cathode ray tube (CRT) to aid the installer or customer when diagnosing the problem. For residential systems, this would entail costs far too excessive to be justifiable and would need to be eliminated. The addition of a setback scheme would also be helpful and may be along the lines of what Honeywell is currently developing.

Another system which relates directly to the problem of setback would be a microcomputer control system which:

1. Has the capability of multiple setback.
2. Senses and memorizes all pertinent information such as outdoor temperature, electricity cost, strip heat capacity, etc.
3. Calculates, at regular intervals, estimated energy savings taking morning recovery into account based on instantaneous computations.
4. Overrides setback or changes amount of setback to insure net energy savings.

Obviously, a large amount of information would be required in such a system. The information needed would differ for every location. Most importantly, the controls would require these amazing capabilities all at a cost effective price.

## Cost Justification

Each control system can be individually evaluated for energy savings and corresponding cost savings. Depending on the ability of the system, each will have an associated maximum cost. By referring to the computer printouts in Appendix B or the graphs in Appendix C, one can see how cost savings differ greatly for every region. The energy savings would probably be greater for a sophisticated microcomputer control system. But based on the data in Appendix B, this study has formulated the following equation as a general rule of thumb:

> "For every dollar saved per year on fuel as a result of setback, $6.45 can be spent on a control system, in order to break even."

Appendix A presents an explanation of the equation which predicts % energy savings.

EXAMPLE:

Heat Pump Capacity = 2.0 tons
Price of Electricity = $.048/kWh
Average Winter Temperature = 35° F
Annual Fuel Cost = $500
Setback (°F) Per Night = 10° (10:00 pm to 6:00 am)

Using the emperical equation, % savings will be 10.85%. Therefore, total dollars saved will be .1085($500)=$54.25. To break even: 54.25 (6.45) = 349.91, or approximately $350.00 could be spent on a control system, completely installed.

## Warranty and Safety Codes

Of dealers and manufacturers contacted, 100% stated there would be no problems associated with the original heat pump warranty or safety codes if additional controls were installed.

## Manufacturers

In regards to a control system capable of insuring setback savings, no manufacturer has actively engaged in the advertisement of such a system. A tremendous amount of advertising literature was gathered at the ASHRAE convention in Chicago in January of 1981. Of all the microcomputer control demonstrations, only one has heat pump setback features and override functions. The SMARTSTAT 1000, manufactured by MSI Control Products, claims the following:

> Savings - "Most important, with its three separate setback programs, the SMARTSTAT 1000 can help you cut back on your consumption of energy... ... by up to 30%, or even more."
>
> Heat Pumps - "In a class by itself, the SMARTSTAT 1000 has been designed to operate with all gas-fired, oil-fired, and electrically powered control heating and cooling equipment... ... as well as all multi-stage heat pump systems currently available."

Replies by salesmen that were questioned indicate that the total installed cost is around $300.00. Using the rule-of-thumb referred to earlier means that the savings would need to be at least $46.50 per year. Carrier, ORNL and Honeywell studies as well as our study, show that this type of savings is achieved only in cold climates such as Minneapolis, Boston, and Chicago (with $10^{o}$ setback). The SMARTSTAT literature estimates a 10% savings for these cold climates using $10^{o}F$ setback. This means the annual energy bill would need to be $465.00 or less to break even. In very few cases is the energy bill for heating this low in these climates.

Clearly, the challenge to the control industry is evident. Cost effective controls are needed. However, with the rapid increase in utility rates, sophisticated controls may become increasingly more justifiable. And as they do, their increasing availability may push the price even lower, making them even more cost effective.

## HEAT PUMP EQUIPMENT

This report has primarily dealt with how setback is affected by controls. The success of a setback scheme is not always attributable to the type of controls. Variations in operating characteristics of the heat pump are very much a factor in savings potential.

### Heat Pump Characteristics Which Effect Setback

The most important characteristic of the heat pump is the capacity.[20] There are many documents which report that the capacity directly and indirectly effects energy consumption. The capacity directly effects energy consumption in the following manner:

Increased capacity → larger compressor → increased energy consumption

The capacity indirectly effects energy consumption in the following manners:

Increased capacity → shorter compressor on-time → lower COP → →increased energy consumption

Increased capacity → less strip heat demanded → decreased energy consumption

The contradiction is that increased capacity increases energy used directly and decreases energy used indirectly. The important factor in correctly sizing the heat pump is building heat load. Building heat load is directly affected by severity of climate. Groff, Bullock and Reedy, of Carrier report that, in general, the correct size for a heat pump is 3.5 to 4 times the structure heating load (for cold climates).[21] For warm climates, the heat pump is sized for cooling. In this manner, the heat pump is not undersized - setback potential savings are critically decreased when the heat pump is undersized. To understand how this occurs, refer to the following example:

HEAT PUMP A -

Capacity = 3.0 tons
COP = 2.8

The balance point of this heat pump will be assumed to be 30°F. Above 30°F, the compressor can supply all the heating needs of the structure. Below 30°F, the strip heat must supplement the compressor.

HEAT PUMP B

Capacity = 2.0 tons
COP = 2.8

Because of the smaller capacity of heat pump B, assume the balance point is 34°F. Remember that the COP, or efficiency, of the electric resistance strip heaters is 1.0. The structure heating load calls for using the strip heat of system A 15% of the time. For the same structure heating load, assume system B must use strip heat 25% of the time. The "system COP" of system A will be:

$$.85\ (2.8) + .15\ (1.0) = 2.53$$

While the "system COP" of system B will be:

$$.75\ (2.8) + .25\ (1.0) = 2.35$$

System A will consume less energy if compressor on-time is not severly hampered. Of course, the drawback, economically speaking, is that larger heat pumps cost more initially. If the facilities engineer is considering setting back the thermostat of a heat pump, the effects of increased capacity are even more important. The morning recovery period is usually the coldest part of the day. In addition, the need for quick recovery for comfort reasons calls for increased use of strip heat. Larger capacities decrease the need for strip heat - increasing system COP. The point is, and it is verified by the energy savings equation given in this report:

"If heat pump capacity is considered large or oversized, then the chances for saving energy by employing night setback are increased."

It should be realized, though, that the proper sizing of a heat pump is critical. The heat pump should not be oversized only because it makes setback more successful. Defrost is also related to heat pump capacity. Carrier Research Division experts report that defrost consumption can be decreased to around 4 to 9 percent of total consumption by properly sizing the heat pump.[22] Another interesting point, only about 2/3 of this is actually a penalty. The rest is accrued as a useful contribution to the heating of the building. Carrier also reports that a properly sized and installed heat pump could be expected to last 15 years. This is a significant increase over the average of 10 years and could account for large savings in an extended life cycle analysis.

Design Changes in Heat Pumps

There are several technologically advanced ideas which would make setback of heat pumps more successful.

Dual stage compressors are currently available to the consumer in most areas of the country.[23] The initial cost is greater; however, their benefits may outweigh the cost, especially as electricity prices continue to climb. Reports indicate that about 90 percent of the year the heat pump capacity is excessive.[24] If the first stage is half the speed of the total compressor speed possible, the following advantages would be obtained:

1. Compressor efficiency is increased.

2. Noise level is reduced 56 percent.
3. Equipment life is increased by reducing mechanical wear.

When the heating requirements of the structure exceed the capacity of the first stage, the second stage would be used. Strip heat would be used when the capacity of the second stage is exceeded. For single stage units currently undersized, the advantage is that the more efficient second stage is used instead of strip heat. For single stage units currently oversized or correctly sized, the advantage is that the first stage is used instead of a more energy consuming one stage compressor.

Another design change to the heat pump is the replacement of electric strip heat with solar supplemental heat. Similar to this is the system of supplementing solar heat with a heat pump. A large amount of research in this area has been conducted, primarily by Dr. Ronald H. Howell of the University of Missouri - Rolla and Warren F. Bessler of General Electric Co. Their conclusions on the subject are similar:

1. Solar systems with supplemental heat pumps are most economical among solar - heat pump systems.
2. Solar - heat pump systems are not cost competitive with heat pump systems, (i.e. solar assistance is not as economical as electric resistance assistance).

Warranty Considerations of Setback Systems

Neither the warranty or the Underwriters Laboratory safety code are in jeopardy if setback of heat pumps is initiated in a prudent style. Only the unauthorized service or tampering of the system could violate the warranty.

In summary, heat pump equipment studies lead to the following conclusions:

1. Setback of heat pumps at night is more economical with oversized systems.
2. Heat pumps should be properly sized to obtain maximum economy.
3. The benefits obtained from properly sizing a heat pump probably outweigh the benefits of setting back an oversized heat pump.
4. Heat pumps with capacity modulation (two stage compressors, etc.) are more efficient than conventional heat pumps. Capacity modulation is advantageous for heat pump systems with night setback.

## RESULTS

This section reviews and interprets the data found in Appendices B and C. The results will be used to formulate final conclusions and recommendations. The Facilities Engineers can use the recommendations to determine their specific setback policies.

DOE Region 1

DOE Region 1 is a cold climate region with expensive fuel. Natural gas is more expensive than in any other DOE region; electricity is second most expensive in DOE Region 1. This combination of cold climate and expensive electricity makes night setback attractive in this area of the country. Appendix B shows life cycle economics for the various DOE regions. Boston was the city from DOE Region 1 which was evaluated. The average winter temperature of 40.0°F is fairly mild for this region. Our studies, based on previous computer simulations show that savings of 4.4 percent in cost can be realized over a 10 year period. Note that investment cost and maintenance cost are equal for the cases shown. Our assumption was that maintenance costs of a setback system would not increase because compressor on-time would increase. This was verified by dealers and manufacturers of heat pumps. Investment cost did not increase because manual setback was assumed. The 226 dollars which would be saved over a ten year period is probably a conservative estimate for DOE Region 1. Colder temperatures and a larger heat pump would only tend to increase total dollar savings. Appendix C is a collection of graphs based on the data in Appendix B. An important point to realize is that the relationship between % savings and amount of setback is not perfectly linear. However, for the interval under study, the relationship shown is adequate for serving as a general guideline. By multiplying the amount of setback, in °F, by the length of setback in hours, the Facilities Engineer may obtain the achievable % savings in energy or cost. Caution should be taken when the degree hours exceeds 80. The "curve" will tend to flatten out after 80, giving less and less savings for increasing setback. The graph associated with two outside thermostats shows an interesting fact. Savings will be increased if outside thermostats are used to control the heat pump auxiliary heat. This fact was apparent throughout the study in all DOE regions, regardless of temperature or price of electricity.

DOE Region 3

The average prices of natural gas and electricity in DOE Region 3 are higher than the national average. The average temperatures are not excessively low-in the neighborhood of 40-45$^{O}$F. The expectation is that setback would be advantageous in DOE Region 3. By examining the life cycle economics in Appendices B and C, the percent savings are indeed seen to be relatively good. An average of around 50 dollars per year could be expected to be saved for a rather large sized heat pump (3.5 tons). The associated life cycle analysis shows a 239 dollar savings over a 10 year period for a system with no outside thermostats and a 336 dollar savings for a system with two outside thermostats. It is clearly an advantage to use outside thermostats to control the use of auxiliary heaters.

DOE Region 4

Atlanta was used as the example city for DOE Region 4. The average electricity price in DOE Region 4 is below the national average and the average winter temperature is 51.7$^{O}$F. The result is small percent cost savings and fairly large percent energy savings. The total energy saved is not that great. Note that only 11-22 dollars can be expected to be saved annually. The graphs of Atlanta's potential savings in Appendix C are similar. For warmer climates it is apparent that varying capacity and setback scheme are not extremely critical to savings potential. Yet thermostat arrangement and heat pump capacity changed drastically; savings did not change.

DOE Region 5

Minneapolis, which is located in DOE Region 5, had the coldest winter temperature of any region in the study. The price of electricity is only very slightly above the national average. Our results show that, although percent energy savings are not great, cost savings and total energy consumption savings will be very good. Minneapolis is well suited for night setback. Total savings in our study are shown to be from around 100 dollars to as much as 500 dollars over a 10 year period. In cold climates, however, care must be taken to insure the comfort of the occupants during morning hours. The problem which exists in cold climates is not evident in a computer simulation. During the morning recovery period when demand is high, the temperature may typically be -10$^{O}$F. The ability of the heat pump to operate at a high COP is severly hampered. More importantly, if supplemental heat is held to a minimum, the morning recovery will be long, causing the occupants to feel uncomfortable. The indication from the graphical presentation of Minneapolis is that a smaller amount of setback would be most logical. Seven or eight degrees seem to be the point where the cost savings graph tends to level off. An added benefit of smaller setback is shorter recovery periods, thereby optimizing the amount of savings with the level of comfort.

DOE Region 6

DOE Region 6 consists of a number of states with comparatively warm climates. Houston has an average winter temperature of 62.0°F and an electricity rate of around $.044/kWh. Both of these parameters are disadvantageous to successful night setback. Notice that percent energy savings are high. This is deceptive. Cost savings percent are only 1.5 and 1.8. Annual heating fuel cost is only reduced by 6 dollars for systems with no outside thermostats and 7 dollars for systems with two outside thermostats. The life cycle cost figures show that only around 50 dollars can be saved over a 10 year period by setting back thermostats ten degrees every night during the heating season. For this reason, heat pump night setback should not be recommended for DOE Region 6 or any other warm climate region.

DOE Region 7

St. Louis, with an average winter temperature of 44.8°F and an electricity rate of $.043/kWh, was chosen to evaluate DOE Region 7. Based on our data, there is good savings potential with night setback in this region. Even though the electricity rate is fairly low and the heat pump capacity small, the cost savings were still 4.2 percent for the outside thermostat systems. Almost two hundred dollars could be saved over a ten year period by setting back 10°F. Most probably, with a larger heat pump, the savings would be even greater.

DOE Region 8

Denver, from DOE Region 8, is similar to St. Louis. The average winter temperature is 40.8°F and electricity costs $.036/kWh. Realizing this is comparatively inexpensive and 40.8°F is not a "cold climate", the expected result would be poor cost savings. On the contrary, our studies indicate a possibility to save over 200 dollars over ten years. The annual savings in energy of 13.5% is very good, considering the heating bill is around 245 dollars annually with a 1.5 ton heat pump. This example is indicative of an important point. Average outdoor temperature has a greater effect on setback cost savings than does electricity cost. High electricity rates do increase potential savings by night setback. Even with low electricity rates, significant savings are possible if the temperature is around 40°F or below.

DOE Region 9

The city under study was Los Angeles. The warm climate and average electricity price are not conducive to successful night setback. Inspection of the graphical and tabular data reveal a very low potential for cost savings. Again, just as in the case with Houston, the energy savings possibilities are around 20%. Yet only 60 dollars is saved during a 10 year period. On this basis, it is assumed night setback should not be implemented in DOE Region 9.

DOE Region 10

DOE Region 10 has the lowest electricity cost of any DOE Region, \$.022/kWh. The average winter temperature in Seattle, the city which was analyzed, is 46.9°F. The effect which these have on potential savings are drastic. Cost savings of only around 150 dollars over 10 years, or 2.6 percent are possible. These results are with an oversized heat pump (3.5 tons), which is normally more of an advantage to night setback.

Other Factors Effecting Life Cycle Cost

Initial purchase and installation cost, along with annual maintenance costs, are the other factors effecting life cycle economics. The capacity of the heat pump has a direct effect on these costs. For instance, in our study, the installed price of a 3.5 ton heat pump was \$4,120. The installed price of a 1.5 ton heat pump was only \$1,830. For warm climates the investment cost is the major portion of the life cycle cost. It is mandatory that the heat pump be sized correctly to avoid excessive prices. Maintenance costs are also decidedly higher for larger capacity heat pumps. The operating and maintenance costs of a 3.5 ton unit are around \$178 while only \$117 must be spent on a 1.5 ton heat pump (base year costs).

In cold regions of the country it is apparent that energy costs make up a substantially large portion of the life cycle cost. The properly sized heat pump is probably most economical. Generally, though, oversized units are conducive to successful setbacks. Therefore, a study to determine the optimum sizing based on setback, defrost, and other important factors would be helpful.

DOE Region Comparisons

Night setback of heat pumps has the best chance for success in the following regions:

DOE Region 1
DOE Region 8,

Night setback would probably benefit the heat pump owner in the following regions:

DOE Region 5
DOE Region 3
DOE Region 7

Night setback is not recommended for the following regions:

DOE Region 10
DOE Region 9
DOE Region 6

## CONCLUSIONS

Heat pump night setback offers a potential for energy savings in the range of 5-10%. The amount is dependent primarily on the outdoor temperature, heat pump capacity, and amount of setback. Because of the variation of these factors among different systems, each heat pump system should be evaluated individually.

More simulation studies and actual field data are needed before reliable and correct assumptions can be made regarding the cost effectiveness of night setback with heat pumps.

Microcomputer controls are not widely available for heat pump systems. They must become available, at a cost competitive price, before setback becomes accepted on a popular basis.

Total cost savings are greatest in regions with cold climates and high electricity rates.

Cost savings may be negligible even if energy savings are achievable due to electricity cost, utility rate schedules, and initial cost of add-on controls.

The benefits of properly sizing a heat pump probably outweigh the benefits of setting back an oversized heat pump.

Heat pumps with capacity modulation are well suited for night setback.

## RECOMMENDATIONS

Until more conclusive data is available regarding heat pump night setback, the following recommendations should serve as general guidelines:

1. Do not set back thermostats if the average winter temperature is greater than 50°F.
2. Do not set back thermostats if the heat pump is not equipped with an outdoor thermostat to control auxiliary heat.
3. Set back thermostats only if the following have been completed:
    a. Percent savings are calculated by using the equation in Appendix A.
    b. Total cost savings are determined by multiplying percent savings by total annual energy bill.
    c. Determination of the benefits of the savings to the facility is made.
    d. The outdoor thermostat is set 2°F above the balance point of the heat pump.

4. Do not purchase a sophisticated control system unless:
   a. The purchase price is substantially less than 6.45 multiplied by annual cost savings and the estimated life is 10 years or more.
   b. A new system becomes available that guarantees percent savings greater than that calculated in (3a)

      AND

      The purchase price is substantially less than 6.45 multiplied by the guaranteed savings times the annual energy bill,

      AND

      the estimated life is 10 years or more.
5. Refer to Appendices B and C to obtain estimates of the life cycle costs of the heat pump system with and without setback.

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## APPENDIX A

### EXPLANATION OF ENERGY SAVINGS PREDICTION EQUATION

$$\% \text{ SAVINGS} = \{.34 - .015\ (\text{cap.})\}\ \text{AWT} + (\text{SB} - 10)\ \{.027\ (\text{SB})^2 - .415\ (\text{SB}) + 1.69\}\ \{.5 + .039\ (65 - \text{AWT})\}$$

Where - cap. = capacity in tons,
SB = Setback in $^{\circ}F$
AWT = Average Winter Temperature in $^{\circ}F$

This equation is an empirical equation used to predict percent savings in energy consumption due to night setback. It assumes the data found in the three computer studies mentioned in this report is accurate and verifiable.

Based on our studies, the following conclusions about the equation can be made:

1. It does not account for a variation in COP, humidity, or type of control scheme.
2. It should be used when the independent variables have the following ranges:

   $1 \text{ ton} < \text{capacity} < 5 \text{ tons}$

   $3\ ^{\circ}F < \text{setback} < 15\ ^{\circ}F$

   $25^{\circ}F < \text{average winter temperature} < 65^{\circ}F$
3. The average error associated with the equation is $\pm$ 11%.
4. The equation can and should be used as an initial guideline for deciding whether heat pump night setback is economical.

APPENDIX B

LIFE CYCLE ECONOMICS OF SETBACK ALTERNATIVES

DEFINITION OF TERMS

Note: Economic period evaluated = 10 years.

1. 1980 Base Fuel Cost - cost per KWH of electricity taken from Federal Register - Part IV, April 30, 1979.
2. Average Winter Temperature - average temperature during heating season of city under study - taken from ASHRAE 1980 Systems - chapter 43.
3. Setback Scheme - NOT = no outside thermostats

   TOT = two outside thermostats

   X/Y = X daytime temperature

   Y setback temperature

   "number before X/Y refers to amount of strip heat in KW"
4. Degree Hours of Setback/Night = AMOUNT OF SETBACK ($^{\circ}$F) multiplied by LENGTH OF SETBACK (hours)
5. Investment Cost = Initial purchase cost + installation cost = $\dfrac{\left[2900\left(\dfrac{\text{desired capacity}}{3}\right)^{.9} + 1400\ (\text{capacity})\right]}{2}$

   The first term in this equation was taken from "Unitary Air-to-Air Heat Pumps" by J.E. Christian of ORNL. The second term is a rule-of-thumb used by heat pump retailers.

6. Base maintenance cost is calculated by using the equation,

Operating and Maintenance Costs = 165 $\left(\frac{\text{capacity}}{3}\right)^{.5}$

taken from "Unitary Air-to-Air Heat Pumps" by J. E. Christian.

7. Base Annual Fuel Cost = 1980 base fuel cost multiplied by annual energy consumption as reported by respective computer simulation.

8. Life Cycle Cost = Investment cost + base maintenance cost (6.6504) + base fuel cost (DOE factor)

The DOE factor is taken from the Federal Register, Part IV and accounts for escalating fuel prices. The factor of 6.6504 is the discount factor associated with a 10 year period and a 10% discount rate plus the amount associated with a 7% increase per year after 5 years.

9. Cost Savings = 100({Life cycle cost of standard system (no setback)}-{life cycle cost of alternate system (with setback)})/life cycle cost of standard system.

10. Energy Savings - taken directly from computer simulation model.

APPENDIX C

GRAPHICAL REPRESENTATION OF SETBACK ECONOMICS

*** SET POINT COST ANALYSIS ***

DOE REGION 1 - BOSTON

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.060 | 0.060 |
| AVERAGE WINTER TEMPERATURE (F) | 40.0 | 40.0 |
| HEAT PUMP CAPAPICTY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | NOT 70/70 | NOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 390. | 355. |
| LIFE CYCLE COST ($) | 5127. | 4901. |
| COST SAVINGS (PERCENT) | | 4.4 |
| ENERGY SAVINGS (PERCENT) | | 9.0 |

*** SET POINT COST ANALYSIS ***

DOE REGION 1 - BOSTON

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.060 | 0.060 |
| AVERAGE WINTER TEMPERATURE (F) | 40.0 | 40.0 |
| HEAT PUMP CAPAPICTY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | TOT 70/70 | TOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 399. | 352. |
| LIFE CYCLE COST ($) | 5185. | 4882. |
| COST SAVINGS (PERCENT) | | 5.9 |
| ENERGY SAVINGS (PERCENT) | | 11.7 |

*** SET POINT COST ANALYSIS ***

DOE REGION 3 - PHILADELPHIA

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.052 | 0.052 |
| AVERAGE WINTER TEMPERATURE (F) | 44.5 | 44.5 |
| HEAT PUMP CAPACICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 64 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 400. | 363. |
| LIFE CYCLE COST ($) | 7386. | 7647. |
| COST SAVINGS (PERCENT) | | 3.0 |
| ENERGY SAVINGS (PERCENT) | | 9.2 |

*** SET POINT COST ANALYSIS ***

DOE REGION 3 - PHILADELPHIA

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.052 | 0.052 |
| AVERAGE WINTER TEMPERATURE (F) | 44.5 | 44.5 |
| HEAT PUMP CAPAPICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/55 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 104 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 400. | 348. |
| LIFE CYCLE COST ($) | 7886. | 7550. |
| COST SAVINGS (PERCENT) | | 4.3 |
| ENERGY SAVINGS (PERCENT) | | 13.1 |

*** SET POINT COST ANALYSIS ***

DOE REGION 4 - ATLANTA

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.044 | 0.044 |
| AVERAGE WINTER TEMPERATURE (F) | 51.7 | 51.7 |
| HEAT PUMP CAPAPICTY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | NOT 70/70 | NOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 99. | 88. |
| LIFE CYCLE COST ($) | 3264. | 3191. |
| COST SAVINGS (PERCENT) | | 2.2 |
| ENERGY SAVINGS (PERCENT) | | 11.6 |

*** SET POINT COST ANALYSIS ***

DOE REGION 4 - ATLANTA

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.044 | 0.044 |
| AVERAGE WINTER TEMPERATURE (F) | 51.7 | 51.7 |
| HEAT PUMP CAPAPICTY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | TOT 70/70 | TOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 99. | 84. |
| LIFE CYCLE COST ($) | 3264. | 3165. |
| COST SAVINGS (PERCENT) | | 3.0 |
| ENERGY SAVINGS (PERCENT) | | 15.1 |

*** SET POINT COST ANALYSIS ***

DOE REGION 4 - ATLANTA

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.044 | 0.044 |
| AVERAGE WINTER TEMPERATURE (F) | 51.7 | 51.7 |
| HEAT PUMP CAPAPICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 64 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 120. | 102. |
| LIFE CYCLE COST ($) | 6099. | 5979. |
| COST SAVINGS (PERCENT) | | 2.0 |
| ENERGY SAVINGS (PERCENT) | | 14.8 |

*** SET POINT COST ANALYSIS ***

DOE REGION 4 - ATLANTA

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.044 | 0.044 |
| AVERAGE WINTER TEMPERATURE (F) | 51.7 | 51.7 |
| HEAT PUMP CAPAPICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/55 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 104 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 120. | 98. |
| LIFE CYCLE COST ($) | 6099. | 5953. |
| COST SAVINGS (PERCENT) | | 2.4 |
| ENERGY SAVINGS (PERCENT) | | 18.2 |

*** SET POINT COST ANALYSIS ***

DOE REGION 5 - MINNEAPOLIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 28.3 | 28.3 |
| HEAT PUMP CAPAPICTY (TONS) | 2.0 | 2.0 |
| SET-BACK SCHEME | NOT 70/70 | NOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 2400. | 2400. |
| BASE MAINTENANCE COST ($/YEAR) | 135. | 135. |
| BASE ANNUAL FUEL COST ($) | 574. | 534. |
| LIFE CYCLE COST ($) | 7064. | 6802. |
| COST SAVINGS (PERCENT) | | 3.7 |
| ENERGY SAVINGS (PERCENT) | | 6.9 |

*** SET POINT COST ANALYSIS ***

DOE REGION 5 - MINNEAPOLIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 28.3 | 28.3 |
| HEAT PUMP CAPAPICTY (TONS) | 2.0 | 2.0 |
| SET-BACK SCHEME | TOT 70/70 | TOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 2400. | 2400. |
| BASE MAINTENANCE COST ($/YEAR) | 135. | 135. |
| BASE ANNUAL FUEL COST ($) | 569. | 513. |
| LIFE CYCLE COST ($) | 7032. | 6664. |
| COST SAVINGS (PERCENT) | | 5.2 |
| ENERGY SAVINGS (PERCENT) | | 9.8 |

*** SET POINT COST ANALYSIS ***

DOE REGION 5 - MINNEAPOLIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 28.3 | 28.3 |
| HEAT PUMP CAPAPICTY (TONS) | 3.0 | 3.0 |
| SET-BACK SCHEME | 17 BASE | 10 KW 4 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 32 |
| INVESTMENT COST ($) | 3550. | 3550. |
| BASE MAINTENANCE COST ($/YEAR) | 165. | 165. |
| BASE ANNUAL FUEL COST ($) | 840. | 820. |
| LIFE CYCLE COST ($) | 10159. | 10028. |
| COST SAVINGS (PERCENT) | | 1.3 |
| ENERGY SAVINGS (PERCENT) | | 2.4 |

*** SET POINT COST ANALYSIS ***

DOE REGION 5 - MINNEAPOLIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 28.3 | 28.3 |
| HEAT PUMP CAPAPICTY (TONS) | 3.0 | 3.0 |
| SET-BACK SCHEME | 17 BASE | 10 KW 10 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 3550. | 3550. |
| BASE MAINTENANCE COST ($/YEAR) | 165. | 165. |
| BASE ANNUAL FUEL COST ($) | 840. | 787. |
| LIFE CYCLE COST ($) | 10159. | 9812. |
| COST SAVINGS (PERCENT) | | 3.4 |
| ENERGY SAVINGS (PERCENT) | | 6.3 |

*** SET POINT COST ANALYSIS ***

DOE REGION 5 - MINNEAPOLIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 28.3 | 28.3 |
| HEAT PUMP CAPAPICTY (TONS) | 3.0 | 3.0 |
| SET-BACK SCHEME | 17 BASE | 17 KW 4 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 32 |
| INVESTMENT COST ($) | 3550. | 3550. |
| BASE MAINTENANCE COST ($/YEAR) | 165. | 165. |
| BASE ANNUAL FUEL COST ($) | 840. | 810. |
| LIFE CYCLE COST ($) | 10159. | 9963. |
| COST SAVINGS (PERCENT) | | 1.9 |
| ENERGY SAVINGS (PERCENT) | | 3.6 |

*** SET POINT COST ANALYSIS ***

DOE REGION 5 - MINNEAPOLIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 28.3 | 28.3 |
| HEAT PUMP CAPAPICTY (TONS) | 3.0 | 3.0 |
| SET-BACK SCHEME | 17 BASE | 17 KW 10 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 3550. | 3550. |
| BASE MAINTENANCE COST ($/YEAR) | 165. | 165. |
| BASE ANNUAL FUEL COST ($) | 840. | 791. |
| LIFE CYCLE COST ($) | 10159. | 9838. |
| COST SAVINGS (PERCENT) | | 3.2 |
| ENERGY SAVINGS (PERCENT) | | 5.9 |

*** SET POINT COST ANALYSIS ***

DOE REGION 5 - MINNEAPOLIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 28.3 | 28.3 |
| HEAT PUMP CAPAPICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 64 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 890. | 825. |
| LIFE CYCLE COST ($) | 11144. | 10717. |
| COST SAVINGS (PERCENT) | | 3.8 |
| ENERGY SAVINGS (PERCENT) | | 7.2 |

*** SET POINT COST ANALYSIS ***

DOE REGION 5 - MINNEAPOLIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 28.3 | 28.3 |
| HEAT PUMP CAPAPICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/55 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 104 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 890. | 798. |
| LIFE CYCLE COST ($) | 11144. | 10540. |
| COST SAVINGS (PERCENT) | | 5.4 |
| ENERGY SAVINGS (PERCENT) | | 10.3 |

*** SET POINT COST ANALYSIS ***

DOE REGION 6 - HOUSTON

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1990 BASE FUEL COST ($/KWH) | 0.044 | 0.044 |
| AVERAGE WINTER TEMPERATURE (F) | 62.0 | 62.0 |
| HEAT PUMP CAPACITY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | NOT 70/70 | NOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 40. | 34. |
| LIFE CYCLE COST ($) | 2904. | 2860. |
| COST SAVINGS (PERCENT) | | 1.5 |
| ENERGY SAVINGS (PERCENT) | | 16.7 |

*** SET POINT COST ANALYSIS ***

DOE REGION 6 - HOUSTON

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.044 | 0.044 |
| AVERAGE WINTER TEMPERATURE (F) | 62.0 | 62.0 |
| HEAT PUMP CAPACITY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | TOT 70/70 | TOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 40. | 33. |
| LIFE CYCLE COST ($) | 2904. | 2852. |
| COST SAVINGS (PERCENT) | | 1.8 |
| ENERGY SAVINGS (PERCENT) | | 18.3 |

*** SET POINT COST ANALYSIS ***

DOE REGION 7 - ST LOUIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.043 | 0.043 |
| AVERAGE WINTER TEMPERATURE (F) | 44.8 | 44.8 |
| HEAT PUMP CAPAPICTY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | NOT 70/70 | NOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 209. | 190. |
| LIFE CYCLE COST ($) | 3945. | 3823. |
| COST SAVINGS (PERCENT) | | 3.1 |
| ENERGY SAVINGS (PERCENT) | | 8.9 |

*** SET POINT COST ANALYSIS ***

DOE REGION 7 - ST LOUIS

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.043 | 0.043 |
| AVERAGE WINTER TEMPERATURE (F) | 44.8 | 44.8 |
| HEAT PUMP CAPACITY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | TOT 70/70 | TOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 205. | 183. |
| LIFE CYCLE COST ($) | 3945. | 3778. |
| COST SAVINGS (PERCENT) | | 4.2 |
| ENERGY SAVINGS (PERCENT) | | 12.5 |

*** SET POINT COST ANALYSIS ***

DOE REGION 8 - DENVER

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.036 | 0.036 |
| AVERAGE WINTER TEMPERATURE (F) | 40.8 | 40.8 |
| HEAT PUMP CAPAPICTY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | NOT 70/70 | NOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 244. | 215. |
| LIFE CYCLE COST ($) | 4235. | 4042. |
| COST SAVINGS (PERCENT) | | 4.6 |
| ENERGY SAVINGS (PERCENT) | | 11.7 |

*** SET POINT COST ANALYSIS ***

DOE REGION 8 - DENVER

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.036 | 0.036 |
| AVERAGE WINTER TEMPERATURE (F) | 40.8 | 40.8 |
| HEAT PUMP CAPAPICTY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | TOT 70/70 | TOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 245. | 212. |
| LIFE CYCLE COST ($) | 4242. | 4022. |
| COST SAVINGS (PERCENT) | | 5.2 |
| ENERGY SAVINGS (PERCENT) | | 13.5 |

*** SET POINT COST ANALYSIS ***

DOE REGION 8 - CHEYENNE

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.036 | 0.036 |
| AVERAGE WINTER TEMPERATURE (F) | 34.2 | 34.2 |
| HEAT PUMP CAPAPICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 64 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 496. | 449. |
| LIFE CYCLE COST ($) | 8611. | 8297. |
| COST SAVINGS (PERCENT) | | 3.6 |
| ENERGY SAVINGS (PERCENT) | | 9.5 |

*** SET POINT COST ANALYSIS ***

DOE REGION 8 - CHEYENNE

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.036 | 0.036 |
| AVERAGE WINTER TEMPERATURE (F) | 34.2 | 34.2 |
| HEAT PUMP CAPAPICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/55 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 104 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 496. | 428. |
| LIFE CYCLE COST ($) | 8611. | 8157. |
| COST SAVINGS (PERCENT) | | 5.3 |
| ENERGY SAVINGS (PERCENT) | | 13.6 |

*** SET POINT COST ANALYSIS ***

DOE REGION 9 - LOS ANGELES

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 60.3 | 60.3 |
| HEAT PUMP CAPAPICTY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | NOT 70/70 | NOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 44. | 38. |
| LIFE CYCLE COST ($) | 2905. | 2864. |
| COST SAVINGS (PERCENT) | | 1.4 |
| ENERGY SAVINGS (PERCENT) | | 14.6 |

*** SET POINT COST ANALYSIS ***

DOE REGION 9 - LOS ANGELES

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.049 | 0.049 |
| AVERAGE WINTER TEMPERATURE (F) | 60.3 | 60.3 |
| HEAT PUMP CAPAPICTY (TONS) | 1.5 | 1.5 |
| SET-BACK SCHEME | TOT 70/70 | TOT 70/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 80 |
| INVESTMENT COST ($) | 1830. | 1830. |
| BASE MAINTENANCE COST ($/YEAR) | 117. | 117. |
| BASE ANNUAL FUEL COST ($) | 45. | 36. |
| LIFE CYCLE COST ($) | 2911. | 2851. |
| COST SAVINGS (PERCENT) | | 2.1 |
| ENERGY SAVINGS (PERCENT) | | 20.0 |

*** SET POINT COST ANALYSIS ***

DOE REGION 10 - SEATTLE

| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.022 | 0.022 |
| AVERAGE WINTER TEMPERATURE (F) | 46.9 | 46.9 |
| HEAT PUMP CAPAPICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/60 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 64 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 151. | 132. |
| LIFE CYCLE COST ($) | 6285. | 6162. |
| COST SAVINGS (PERCENT) | | 2.0 |
| ENERGY SAVINGS (PERCENT) | | 12.3 |

*** SET POINT COST ANALYSIS ***

DOE REGION 10 - SEATTLE

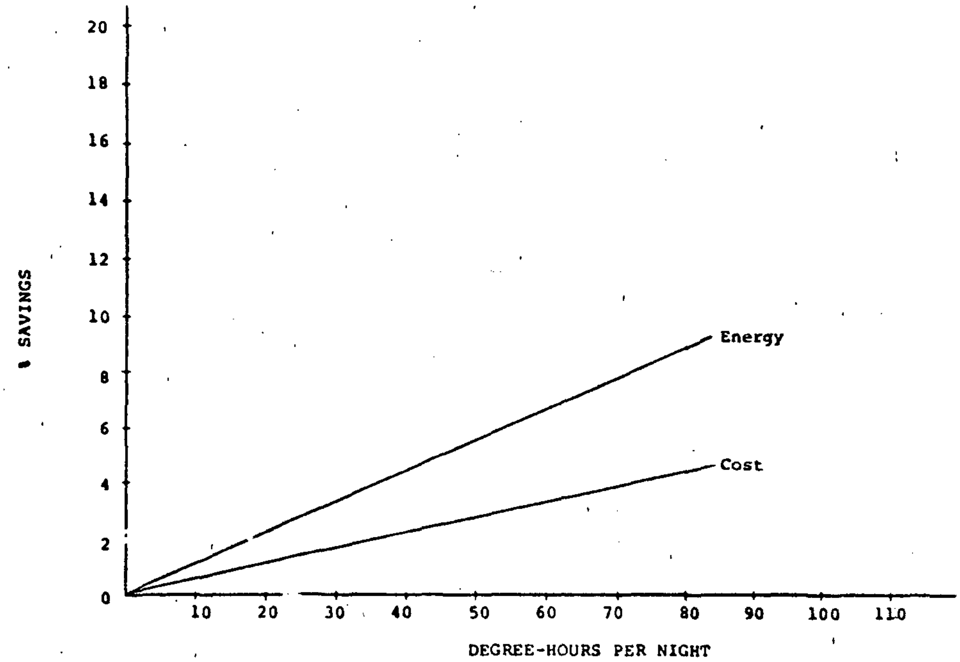
| | STANDARD | ALTERNATIVE |
|---|---|---|
| 1980 BASE FUEL COST ($/KWH) | 0.022 | 0.022 |
| AVERAGE WINTER TEMPERATURE (F) | 46.9 | 46.9 |
| HEAT PUMP CAPAPICTY (TONS) | 3.5 | 3.5 |
| SET-BACK SCHEME | 18 68/68 | 18 68/55 |
| DEGREE HOURS OF SET-BACK/NIGHT | 0 | 104 |
| INVESTMENT COST ($) | 4120. | 4120. |
| BASE MAINTENANCE COST ($/YEAR) | 178. | 178. |
| BASE ANNUAL FUEL COST ($) | 151. | 126. |
| LIFE CYCLE COST ($) | 6285. | 6123. |
| COST SAVINGS (PERCENT) | | 2.6 |
| ENERGY SAVINGS (PERCENT) | | 16.5 |

APPENDIX C

GRAPHICAL PRESENTATION OF SETBACK ECONOMICS

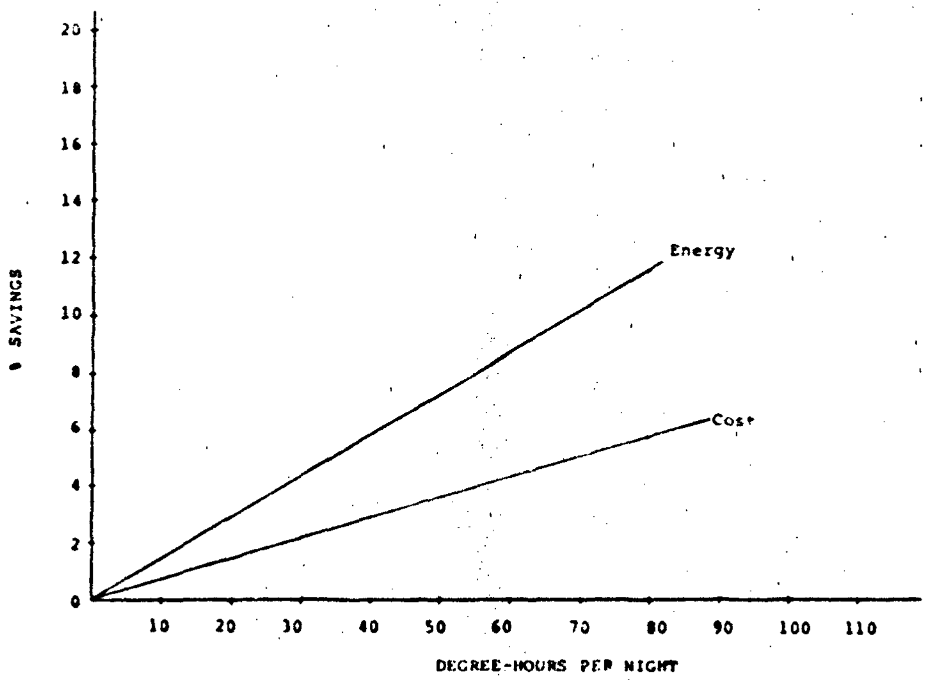
% Savings as a Function of Degree-Hours Per Night of Setback

Boston - 1½ Ton System - No Outdoor Thermostats



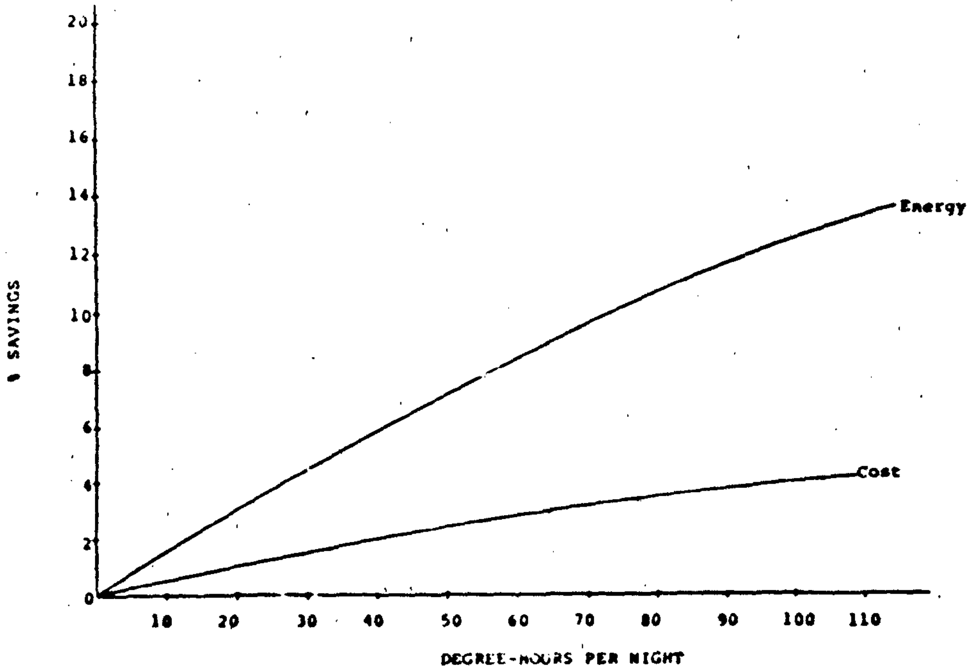
% Savings as a Function of Degree-Hours per Night of Setback

Boston - 1½ Ton System - Two Outdoor Thermostats



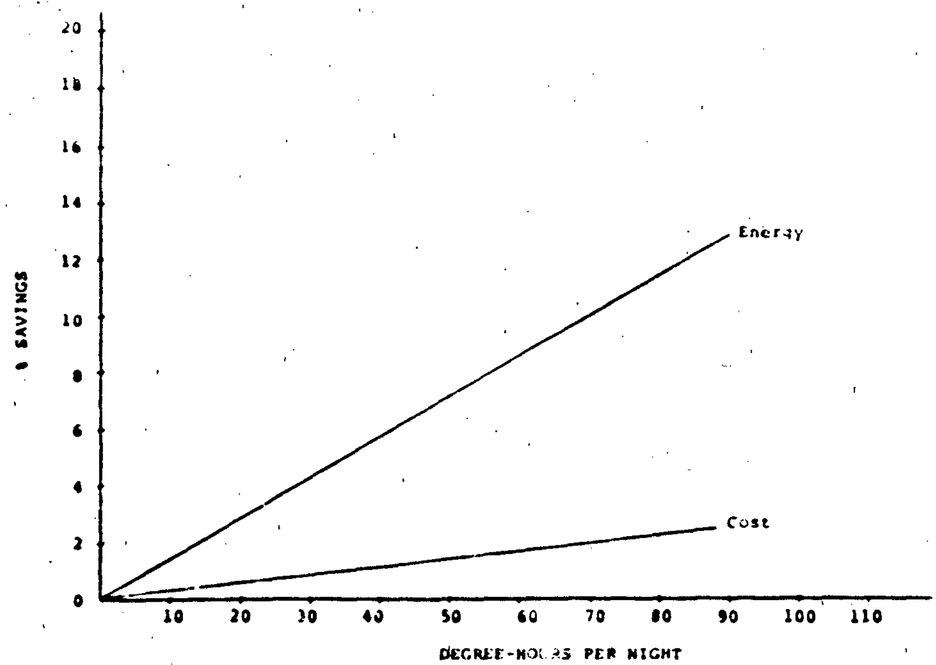
% Savings as a Function of Degree-Hours Per Night of Setback

Philadelphia - 35 Ton System



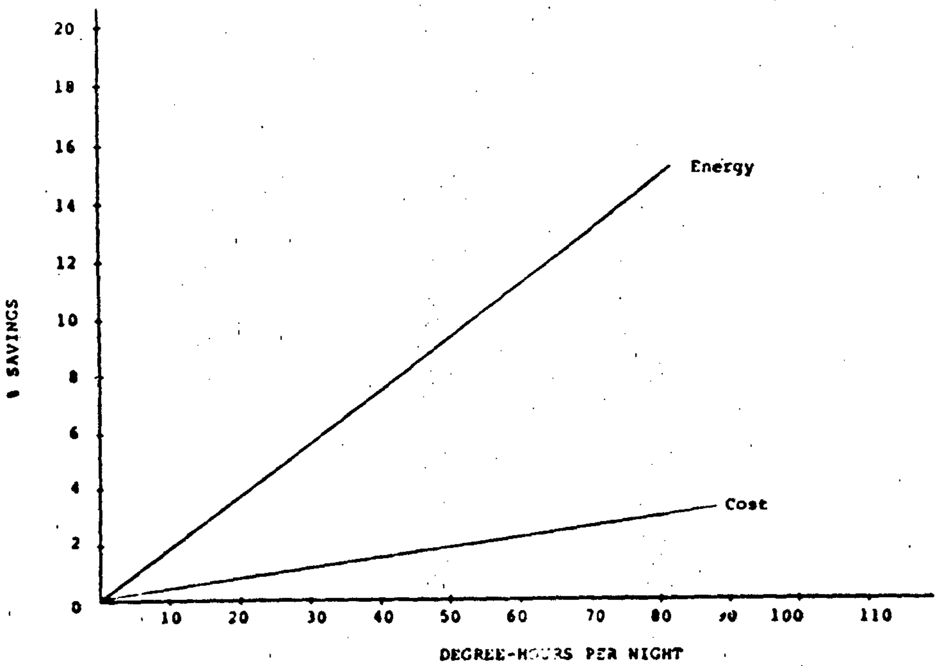
% Savings as a Function of Degree-Hours Per Night of Setback

Atlanta - 15 Ton System - [illegible] Thermostats



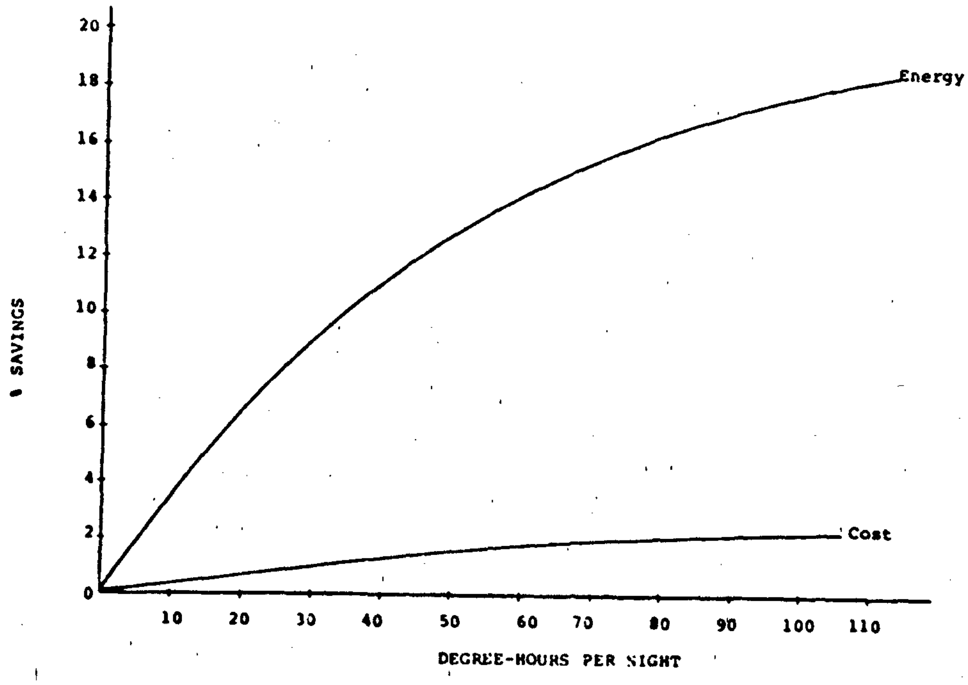
% Savings as a Function of Degree-hours Per Night of Setback

Atlanta - 1½ Ton System - Two Outdoor Thermostats

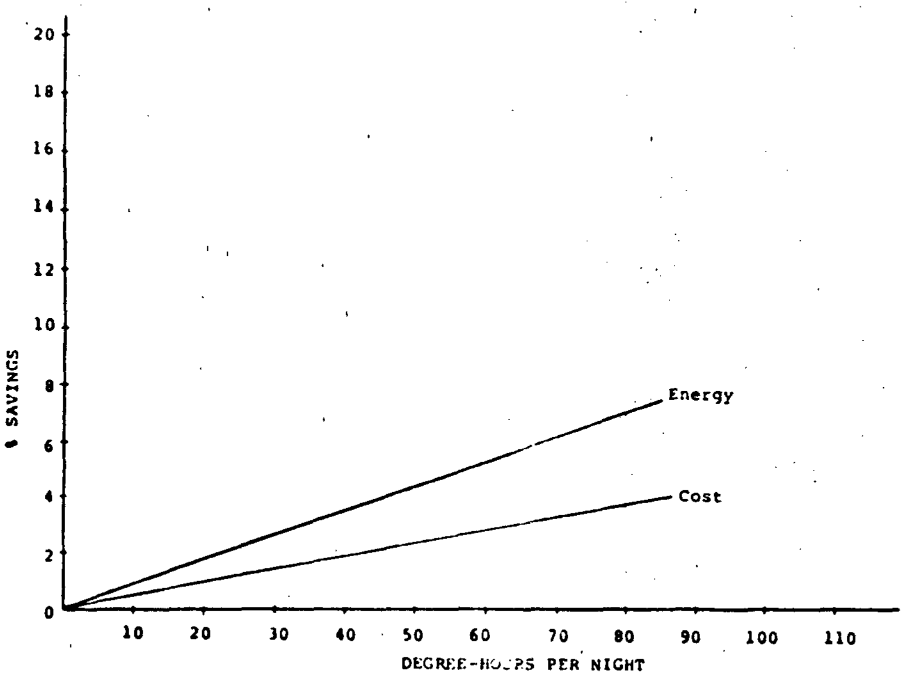


% Savings as a Function of Degree-Hours Per Night of Setback

Atlanta - 3½ Ton System

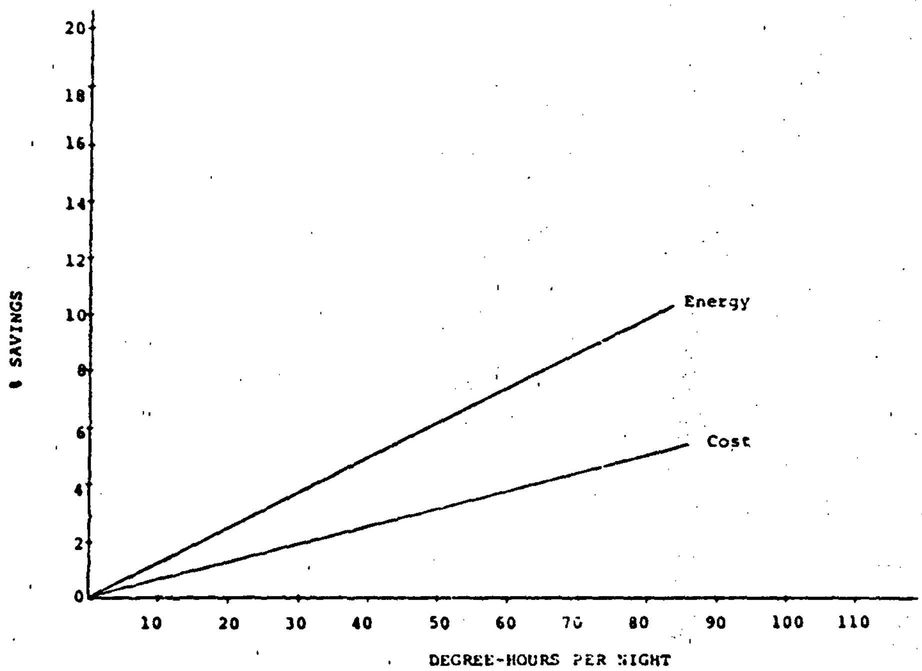


% Savings as a Function of Degree-Hours Per Night of Setback
Minneapolis - 2.0 Ton System - No Outdoor Thermostats



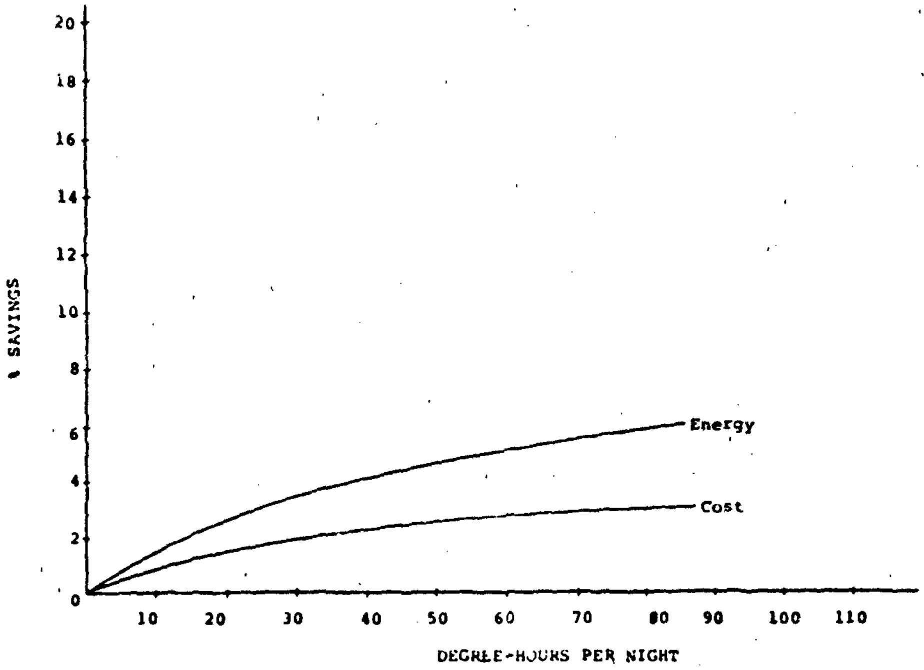
% Savings as a Function of Degree-Hours per Night of Setback

Minneapolis - 2 Ton System - Two Outdoor Thermostats



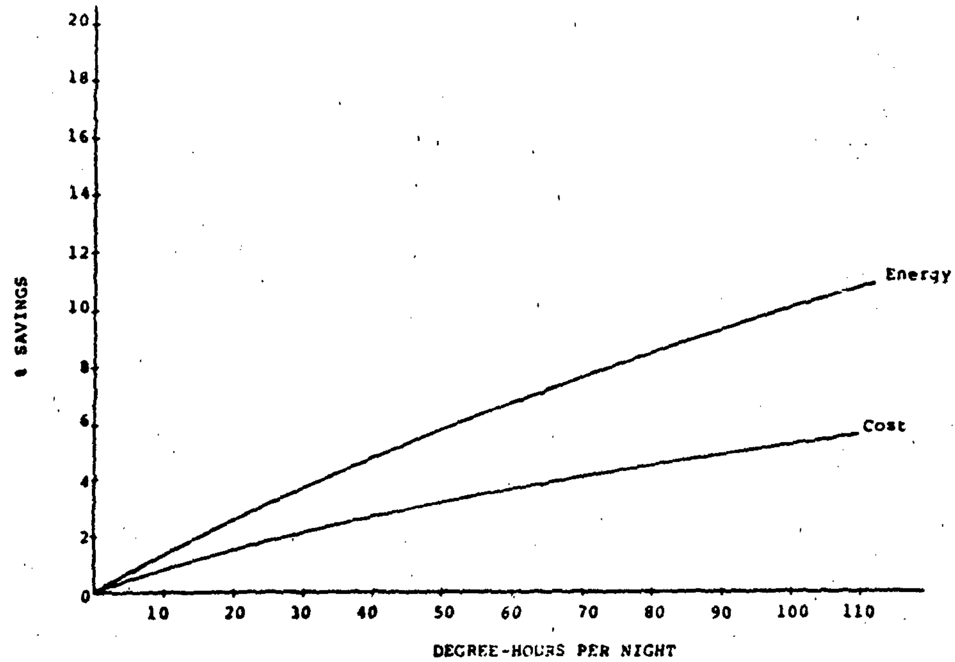
% Savings as a Function of Degree-Hours Per Night of Setback

Minneapolis - 3.0 Ton System



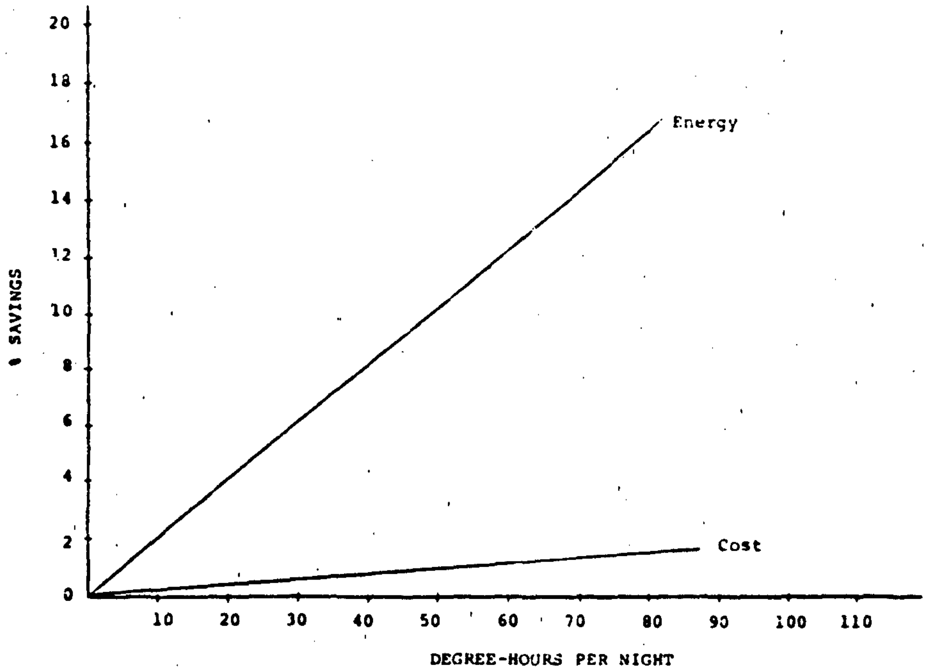
% Savings as a Function of Degree-Hours Per Night of Setback

Minneapolis - 3½ Ton System



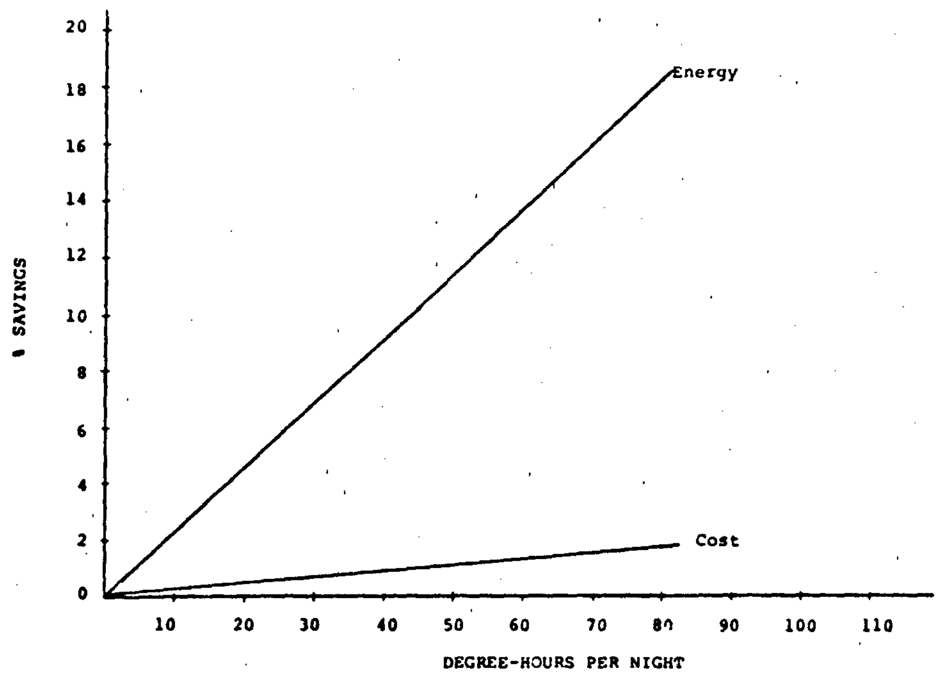
% Savings as a Function of Degree-Hours Per Night of Setback

Houston - 1½ Ton System - No Outdoor Thermostats



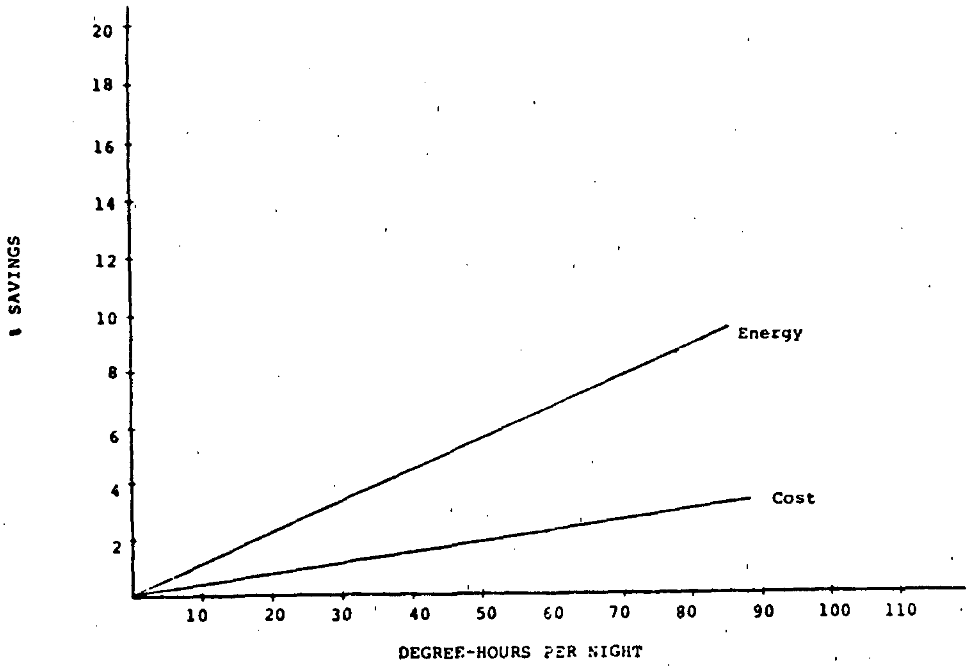
% Savings as a Function of Degree-Hours Per Night of Setback

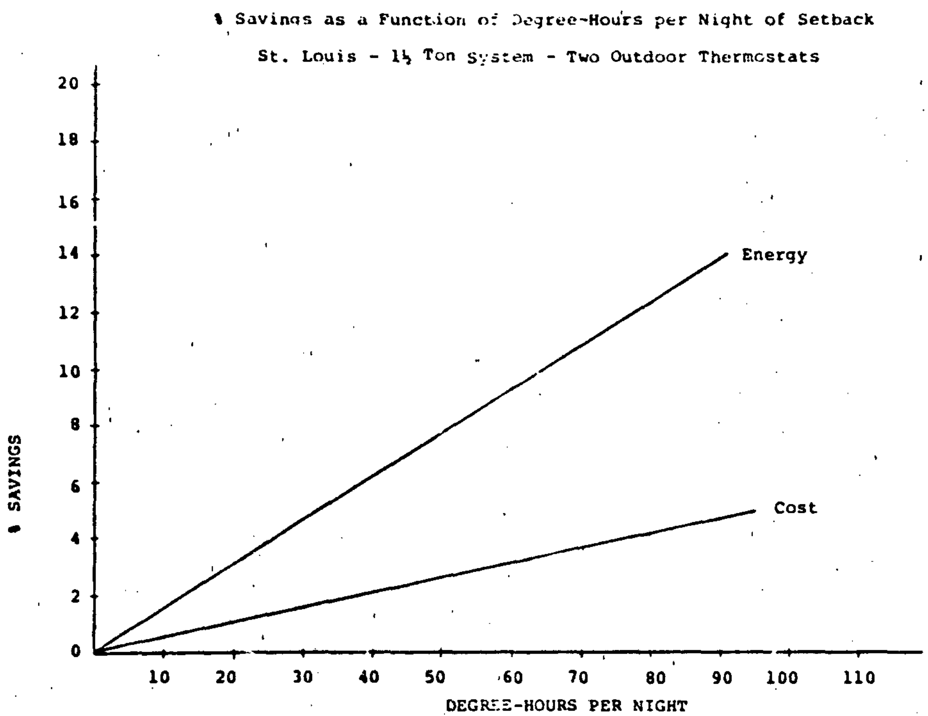
Houston - 1½ Ton System - Two Outdoor Thermostats



% Savings as a Function of Degree-Hours
per Night of Setback

St. Louis - 1½ Ton System - No Outdoor Thermostats

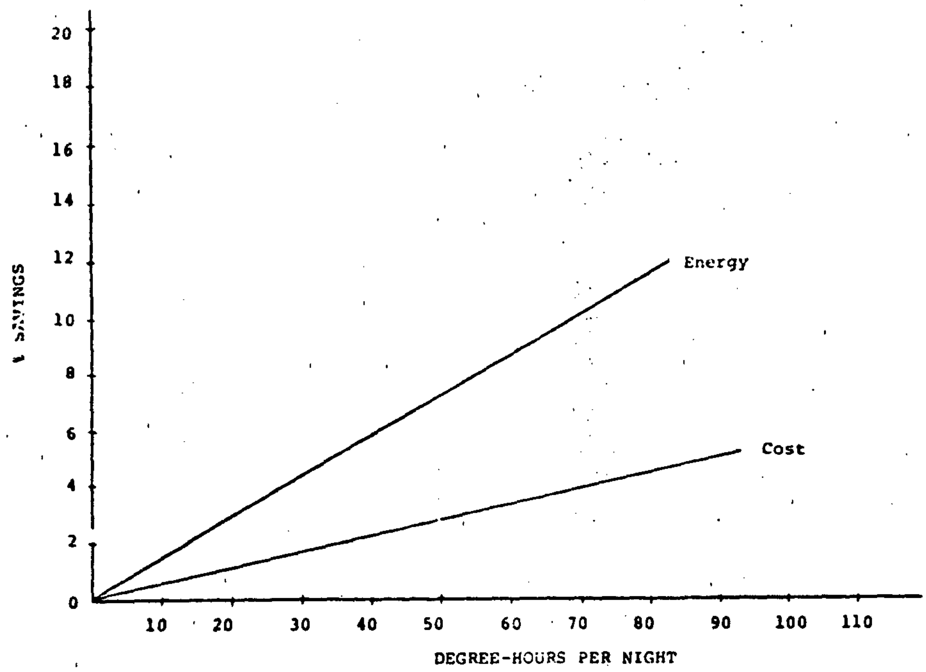




% Savings as a Function of Degree-Hours per Night of Setback
St. Louis - 1½ Ton System - Two Outdoor Thermostats
% SAVINGS
0
2
4
6
8
10
12
14
16
18
20
Energy
Cost
10
20
30
40
50
60
70
80
90
100
110
DEGREE-HOURS PER NIGHT

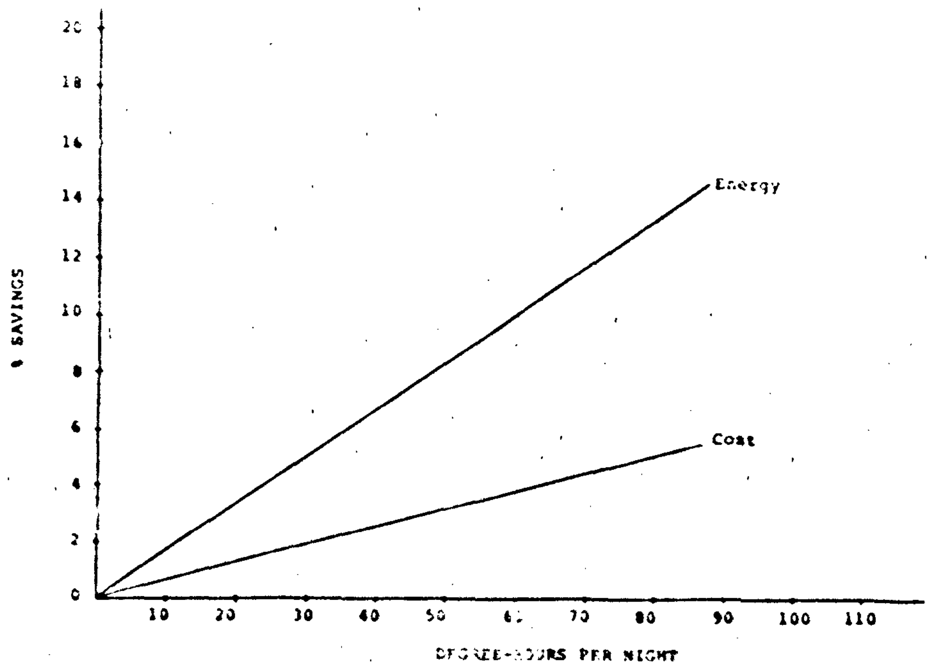
% Savings as a Function of Degree-Hours Per Night of Setback

Denver - 1½ Ton System - No Outdoor Thermostats



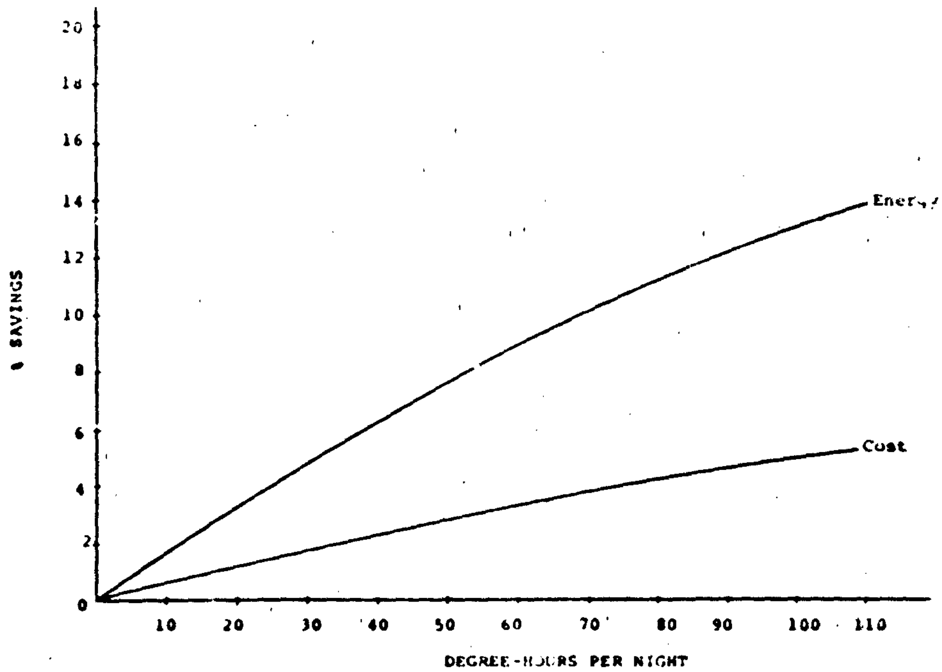
% Savings as a Function of Degree-Hours per Night of Setback

Denver - 1½ Ton System - Two Outdoor Thermostats



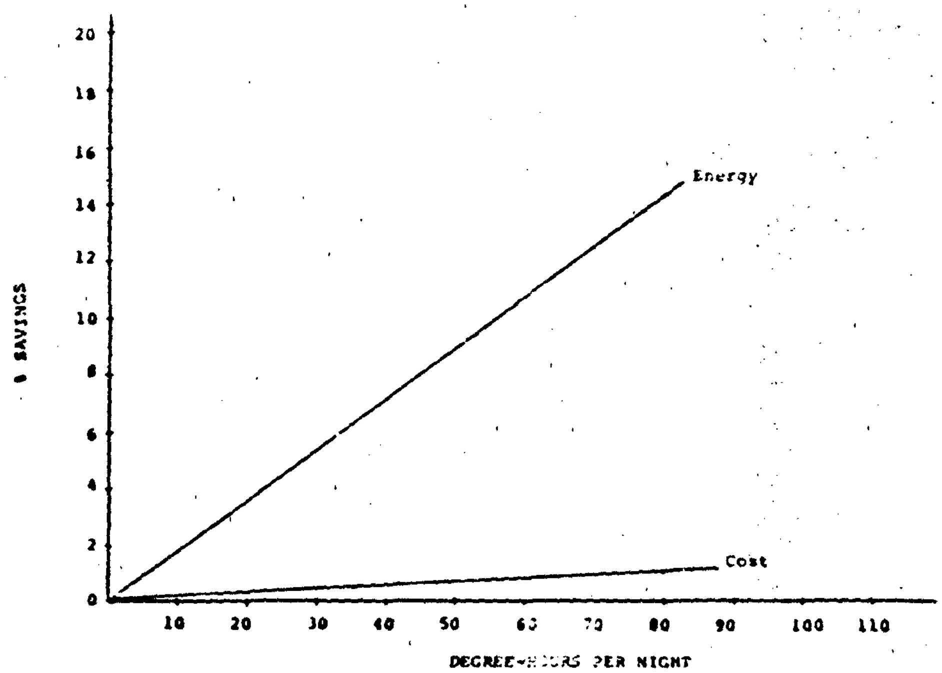
% Savings as a Function of Degree-Hours Per Night of Setback

Cheyenne - 35 Ton System



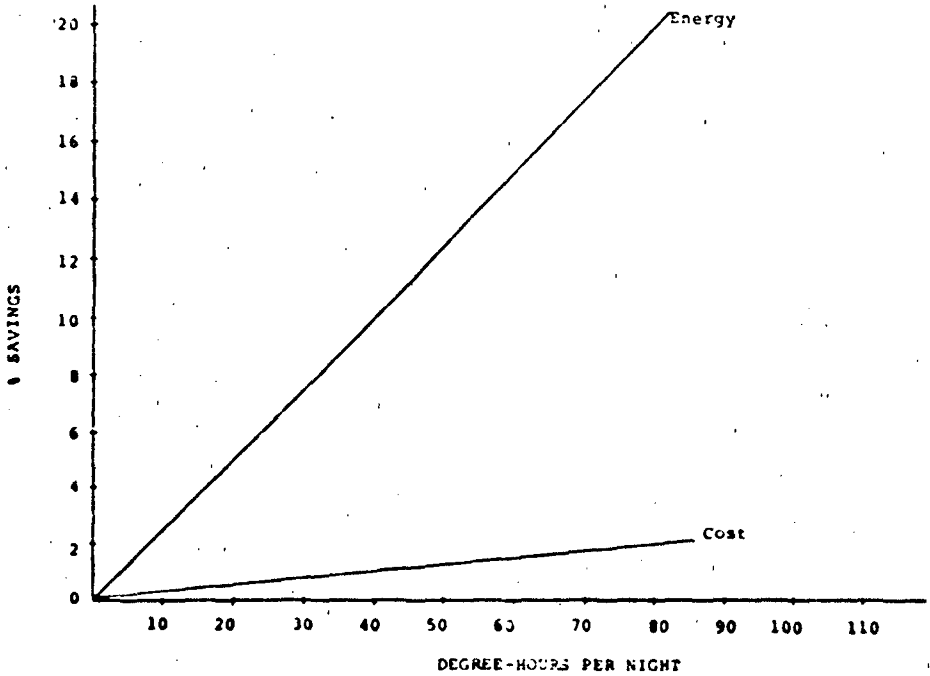
$ Savings as a Function of Degree-Hours Per Night of Setback

Los Angeles - 1½ Ton System - No Outdoor Thermostat



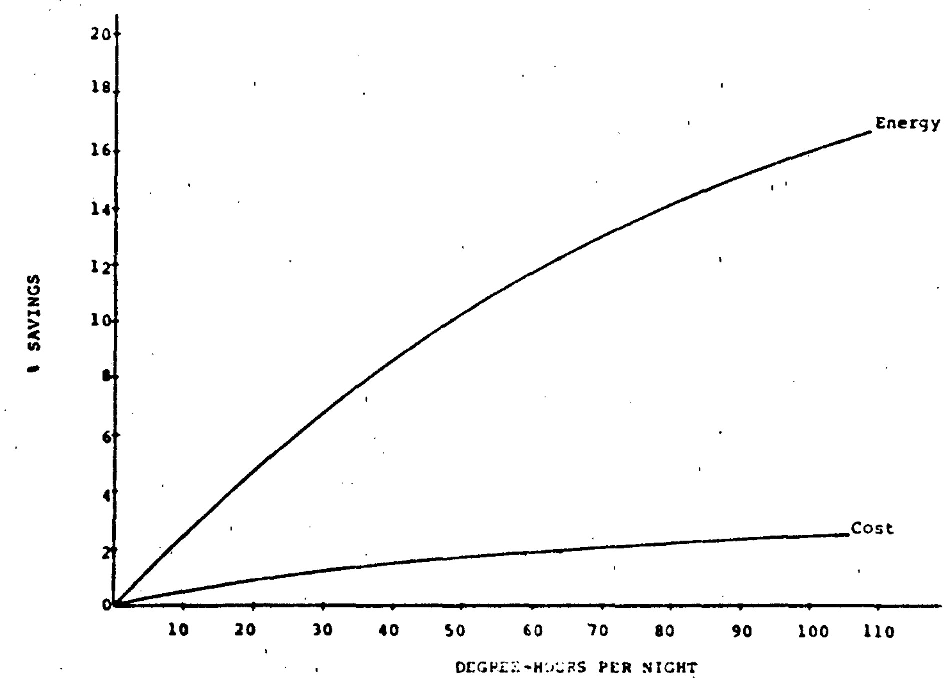
% Savings as a Function of Degree-Hours Per Night of Setback

Los Angeles - 1½ Ton System - Two Outdoor Thermostats



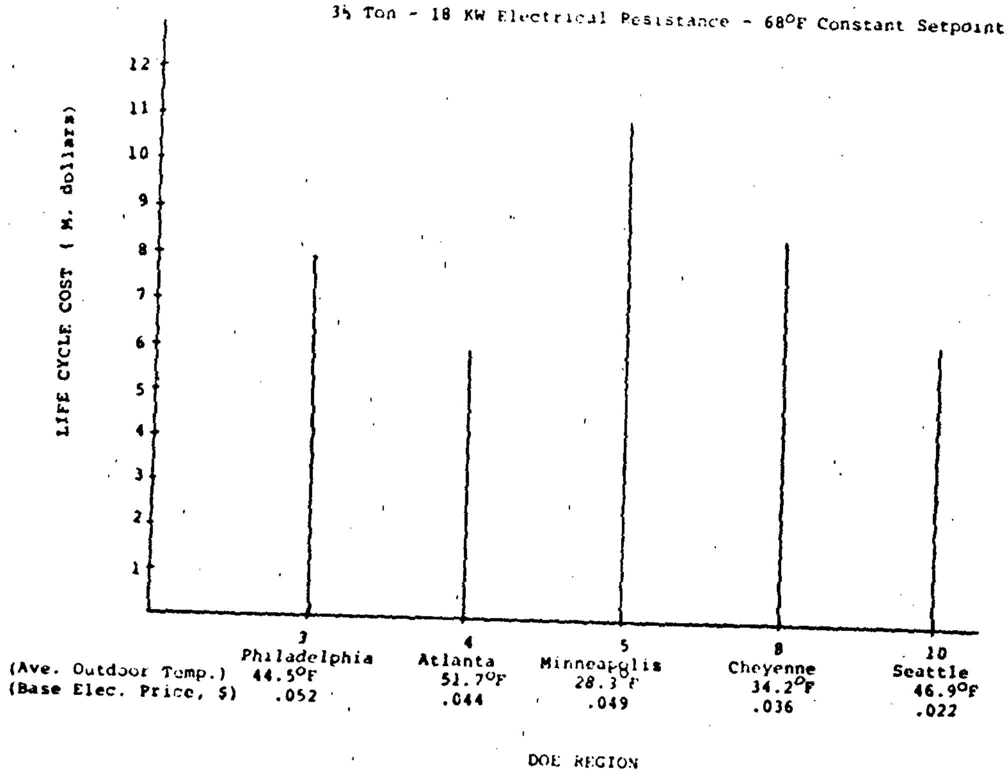
% Savings as a Function of Degree-Hours Per Night of Setback

Seattle - [illegible] Ton System



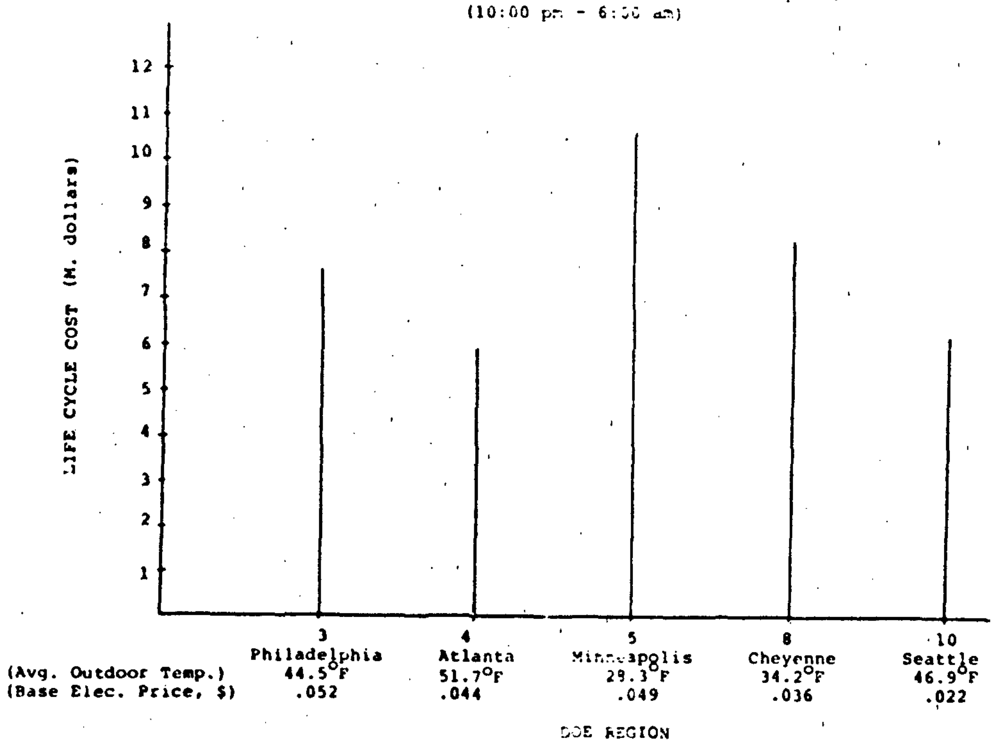
LIFE CYCLE COST AS A FUNCTION OF AVERAGE OUTDOOR TEMPERATURE AND BASE ELECTRICITY COST

3½ Ton - 18 KW Electrical Resistance - 68°F Constant Setpoint



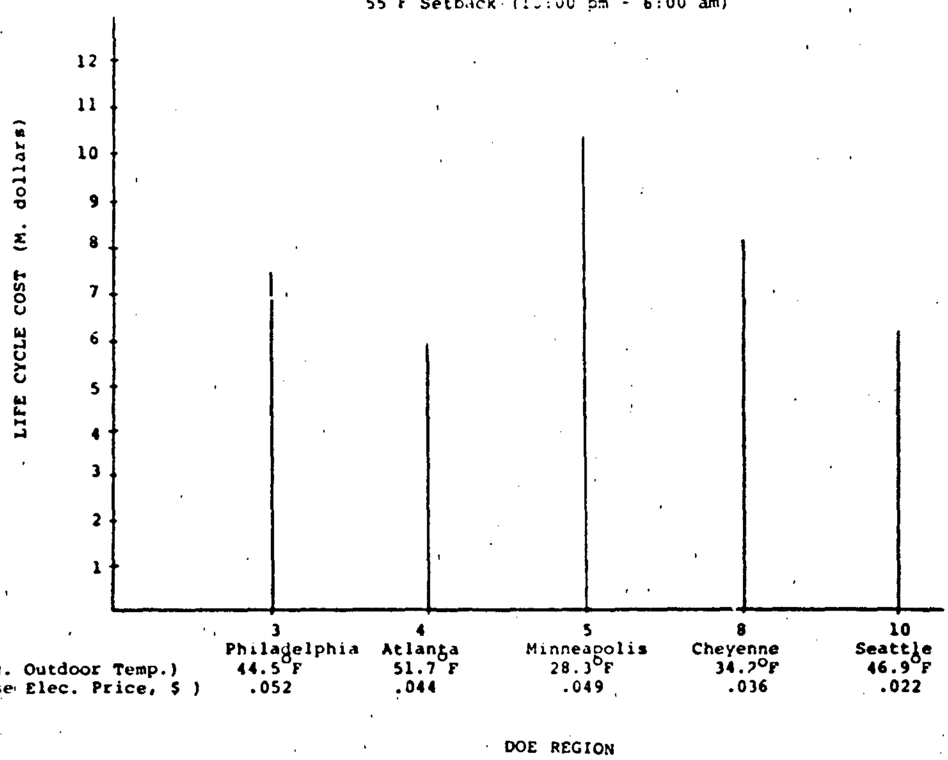
LIFE CYCLE COST AS A FUNCTION OF AVERAGE
OUTDOOR TEMPERATURE AND BASE ELECTRICITY COST

3½ Ton - 18 KW Electric Resistance - 68°F Setpoint - 60°F Setback
(10:00 pm - 6:00 am)



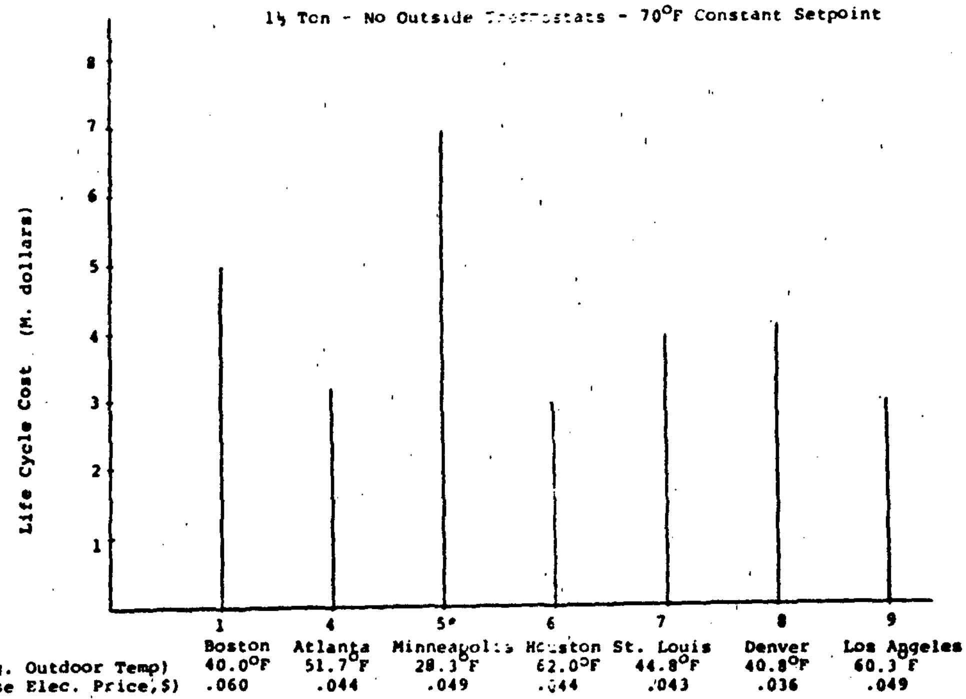
LIFE CYCLE COST AS A FUNCTION OF AVERAGE OUTDOOR TEMPERATURE AND BASE ELECTRICITY COST

3½ Ton - 18 KW Electric Resistance - 68°F Setpoint - 55°F Setback (10:00 pm - 6:00 am)



LIFE CYCLE COST AS A FUNCTION OF AVERAGE
OUTDOOR TEMPERATURE AND BASE ELECTRICITY COST

1½ Ton - No Outside Thermostats - 70°F Constant Setpoint

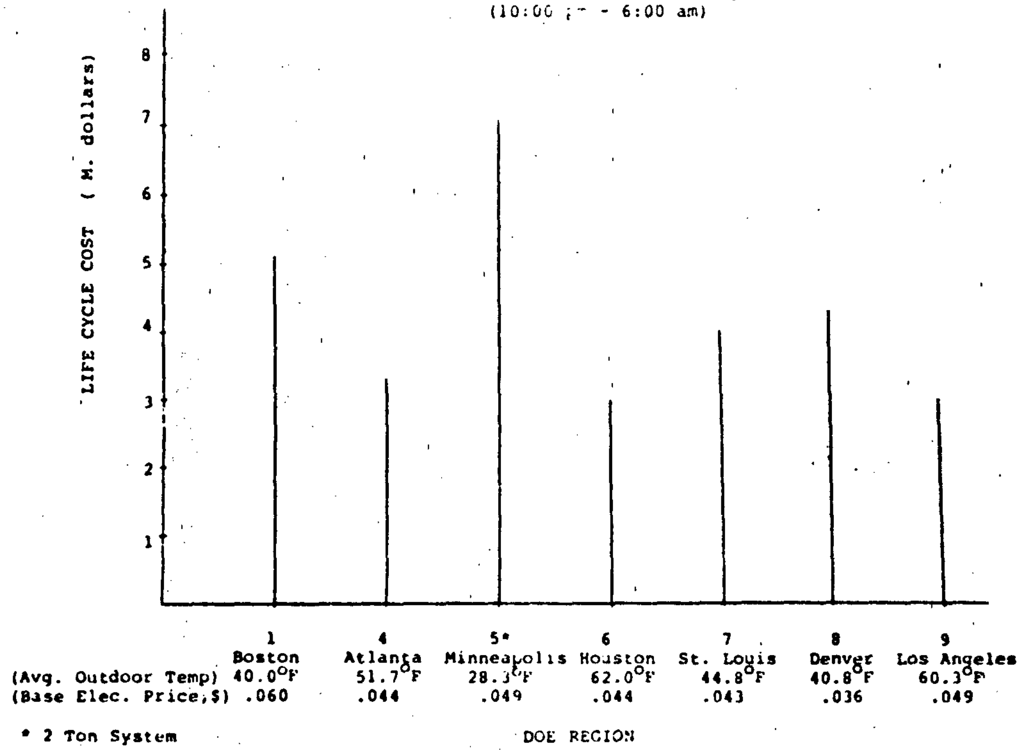



* 2 Ton System

DOE REGION

LIFE CYCLE COST AS A FUNCTION OF AVERAGE
OUTDOOR TEMPERATURE AND BASE ELECTRICITY COST

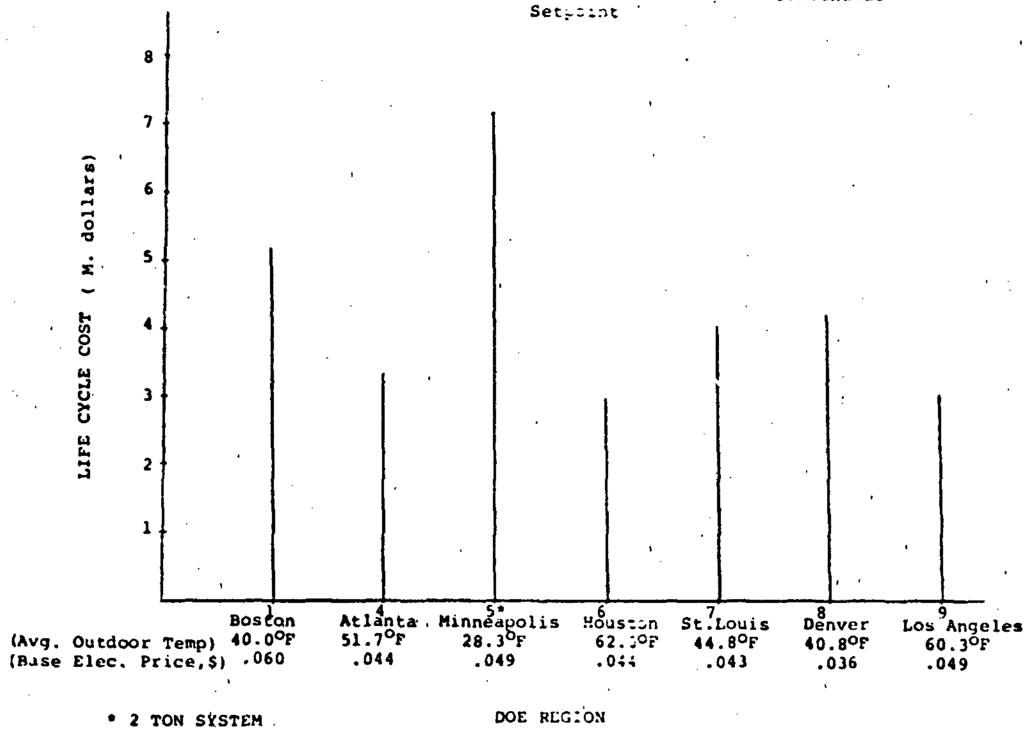
1½ Ton - No Outside Thermostats - 70°F Setpoint - 60°F Setback
(10:00 pm - 6:00 am)




* 2 Ton System

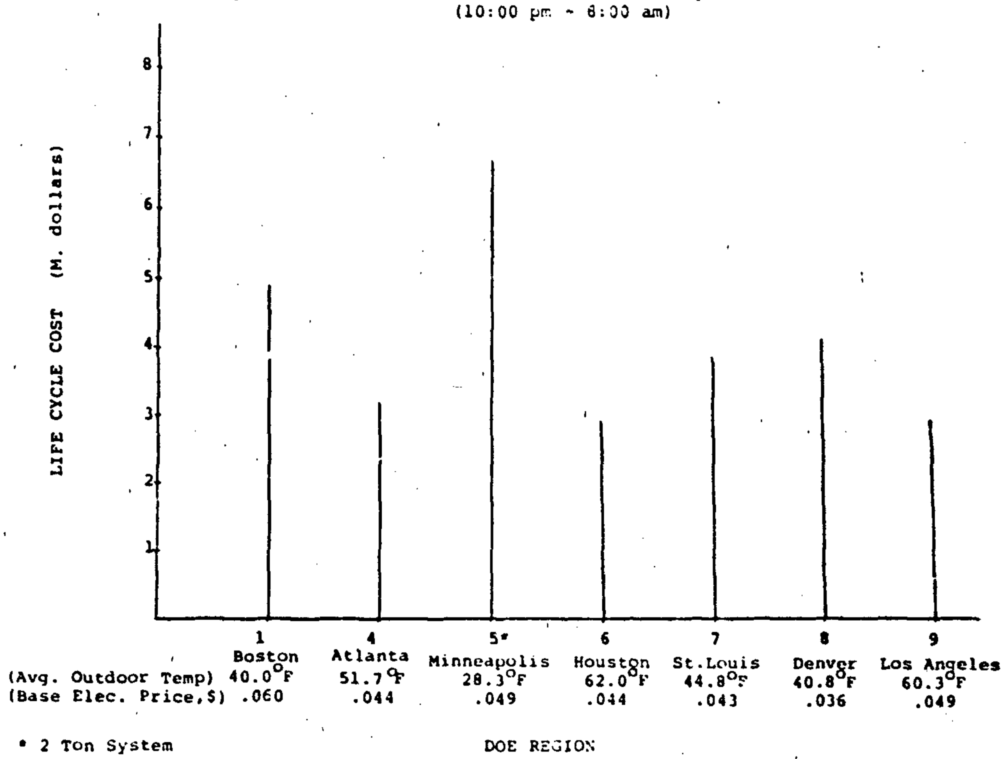
LIFE CYCLE COST AS A FUNCTION OF AVERAGE OUTDOOR TEMPERATURE AND BASE ELECTRICITY COST

1½ Ton - Two Outside Thermostats - 70°F Continuous Setpoint



LIFE CYCLE COST AS A FUNCTION OF AVERAGE
OUTDOOR TEMPERATURE AND BASE ELECTRICITY COST

1½ Ton - Two Outside Thermostats - 70°F Setpoint - 60°F Setback
(10:00 pm - 6:00 am)




* 2 Ton System

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